

Edition 3 Cloud Algorithm Development & Validation Using CALIPSO/CloudSat

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CERES Science Team Meeting, Victoria, BC

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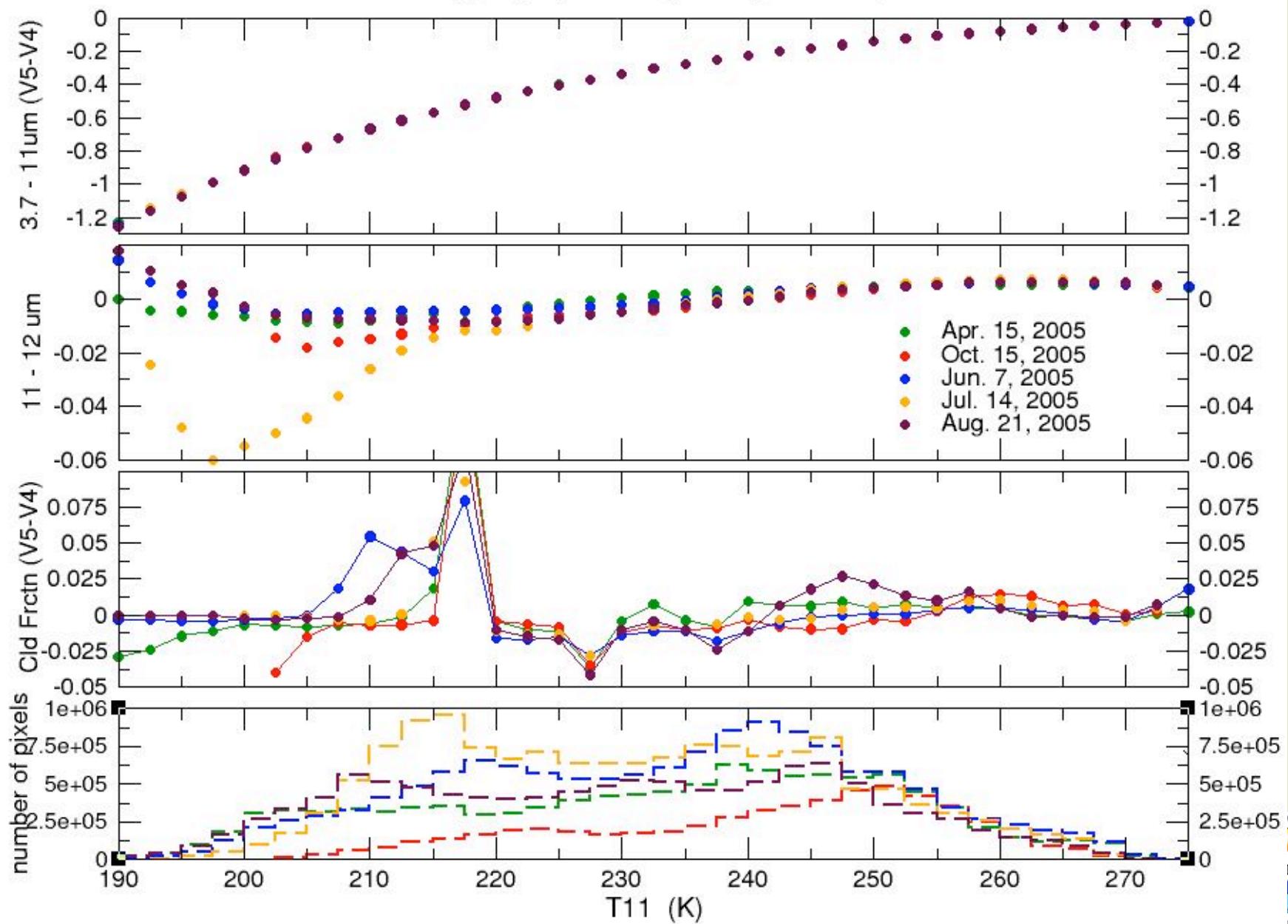
CERES Cloud Activities & Plans

- Complete Terra Ed2 and Aqua Ed1 through 2007
 - *Deal with Collection 4 and 5 differences*
 - *GEOS-4 to end December 2007 (10/06 completed)*
- Examine impacts of changes from GEOS-4 to MERRA
- Refine & test changes for Edition 3
 - *Use CALIPSO-CloudSat & GLAS data*
 - *Field program & surface site data*
- Prepare & submit papers on algorithms, validation, calibration, science



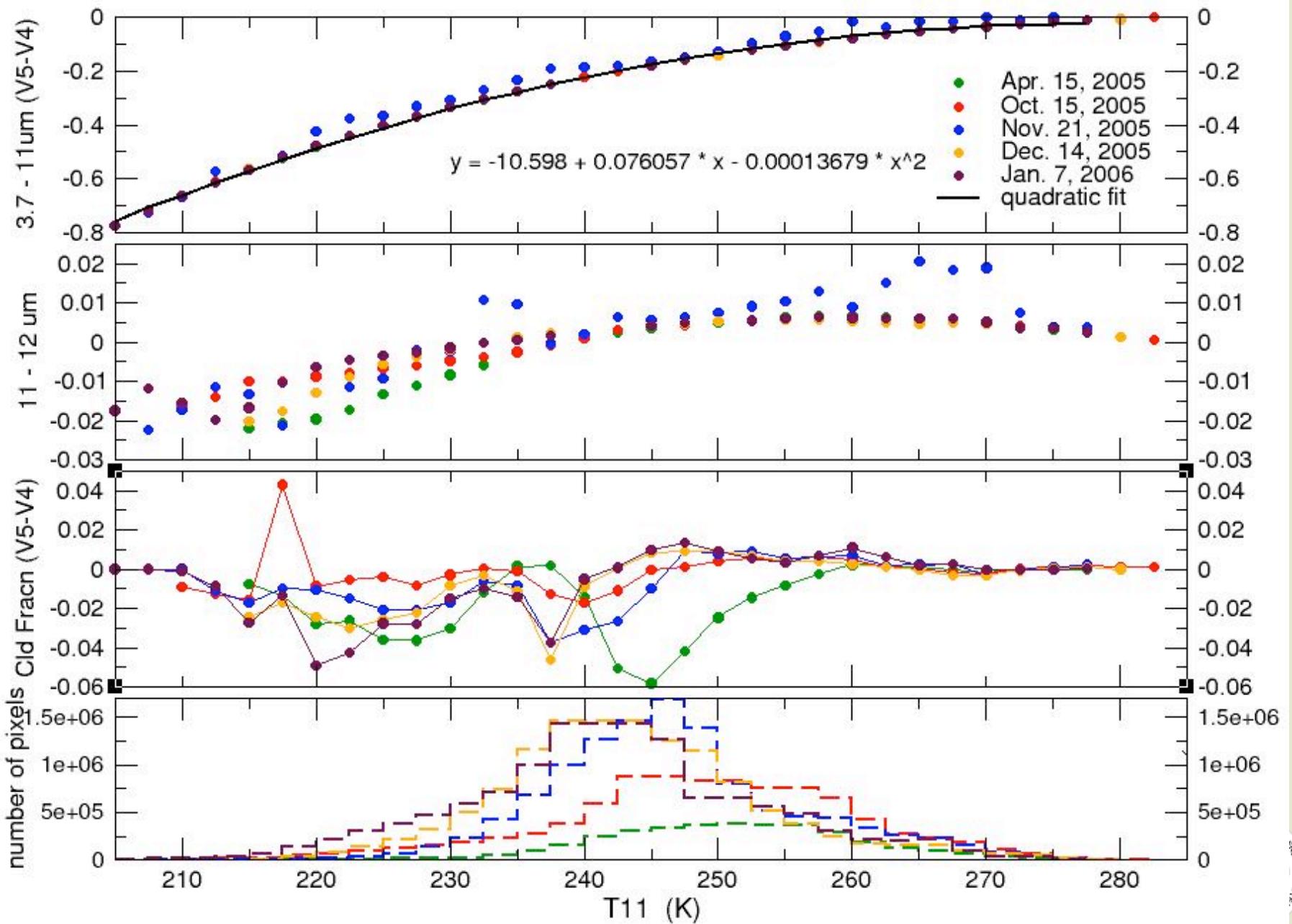
Aqua BTD and Cloud Fraction Comparison between Collection 4 and 5 Radiance Data

Bin to 2.5 deg, Night (SZA > 91), All sky, Antarctic, Lat < -60



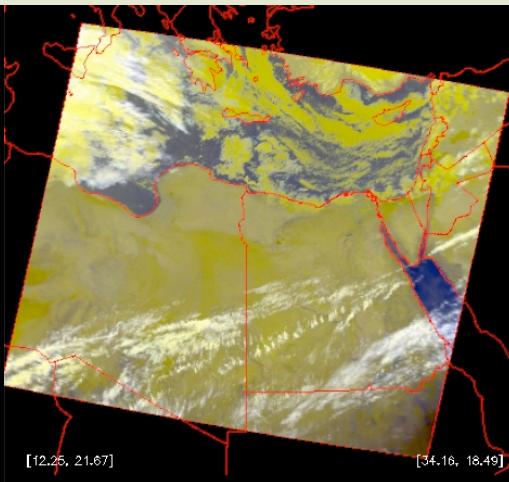
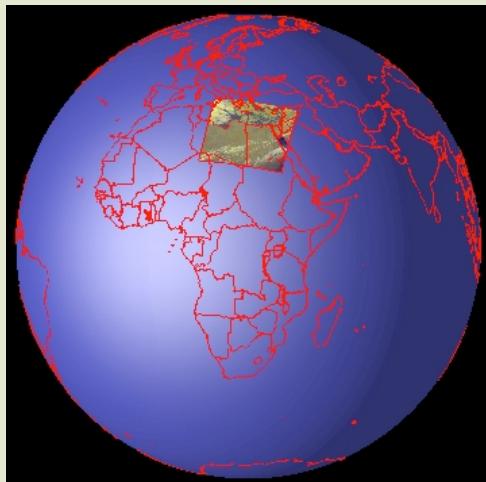
Aqua BTD and Cloud Fraction Comparison between Collection 4 and 5 Radiance Data

Bin to 2.5 deg, Night (SZA > 91), All sky, Arctic, Lat > 60

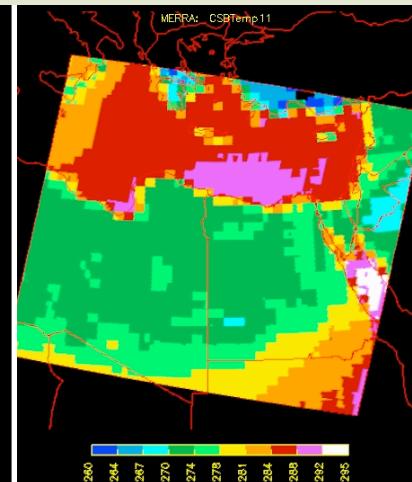


GEOS4 and MERRA Comparison

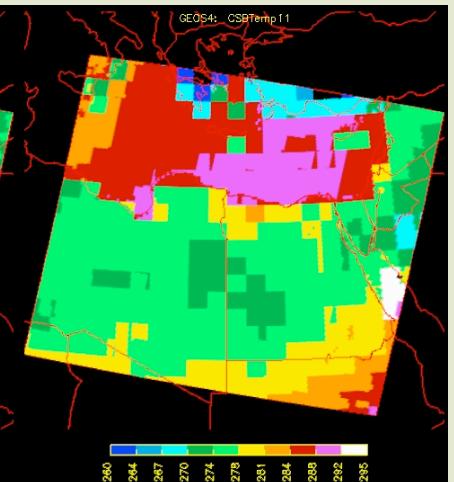
Aqua MODIS, Jan 27, UTC 00



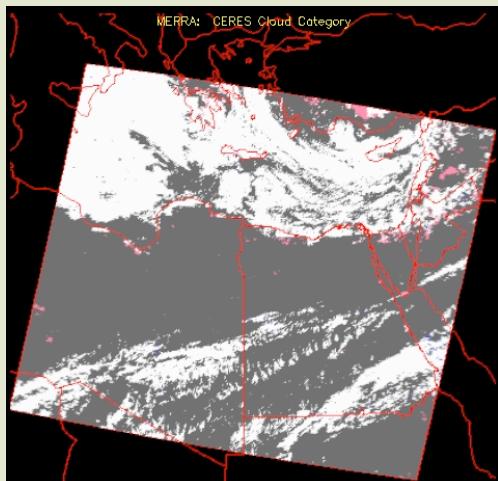
Merra Tcs



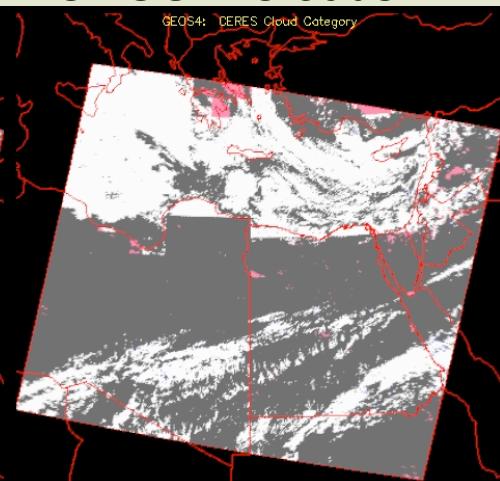
GEOS-4 Tcs



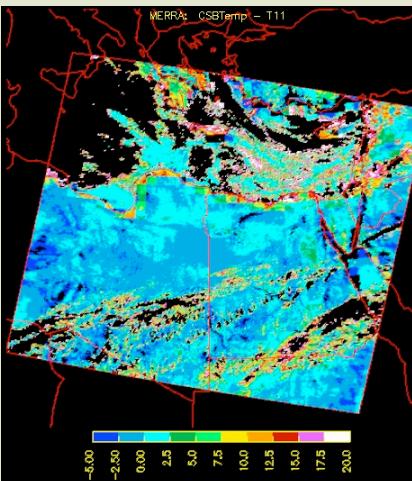
Merra Clouds



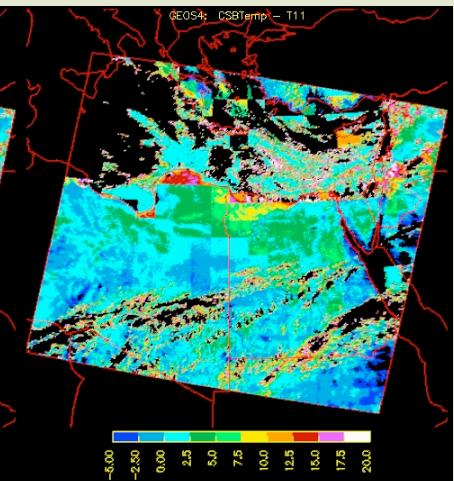
GEOS-4 Clouds



Merra ΔT



GEOS-4 ΔT

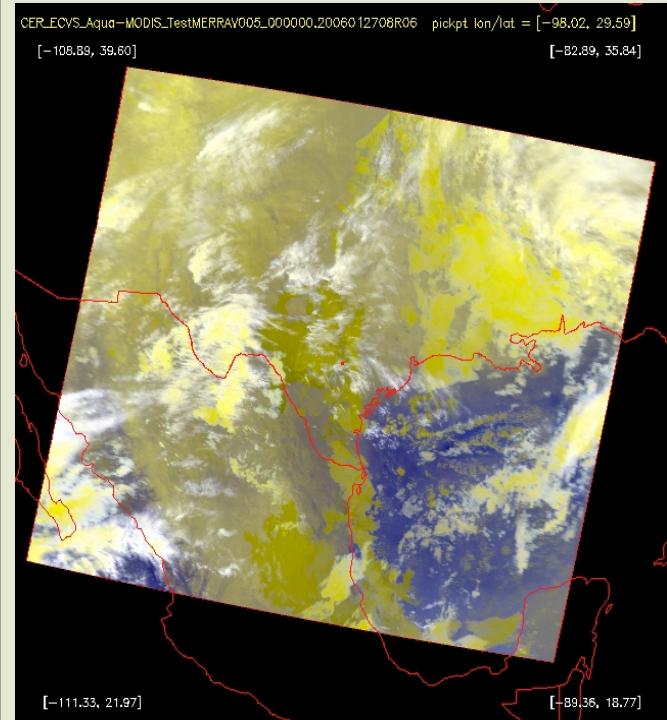


- Better resolution from Merra, helps coastlines, polar regions
- Cloud fractions change, but results no worse, possibly better

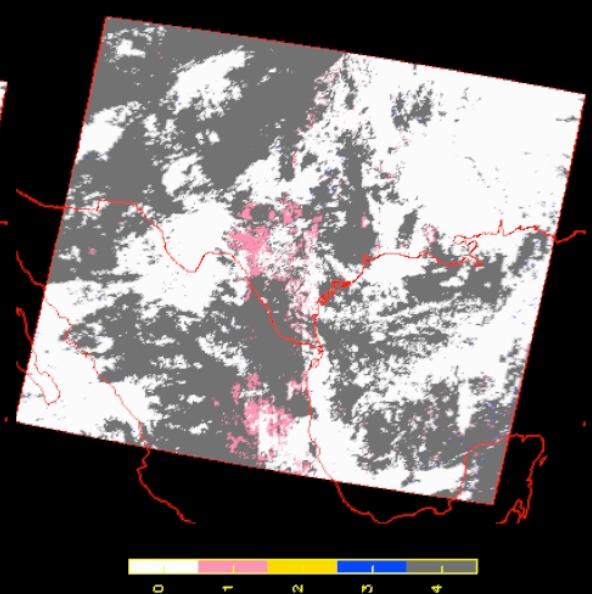
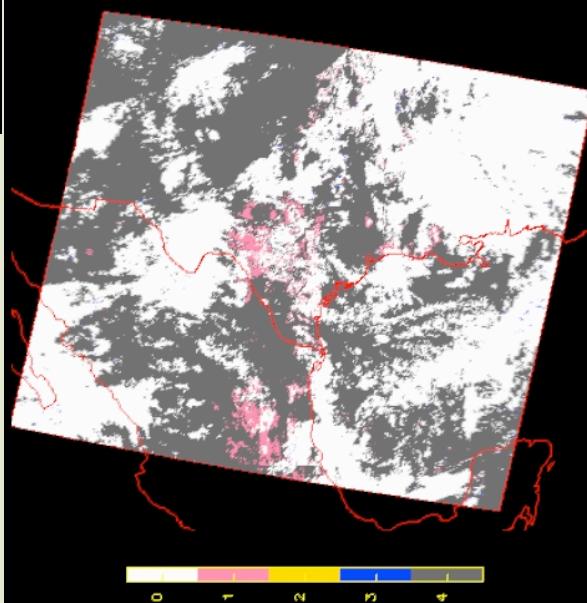
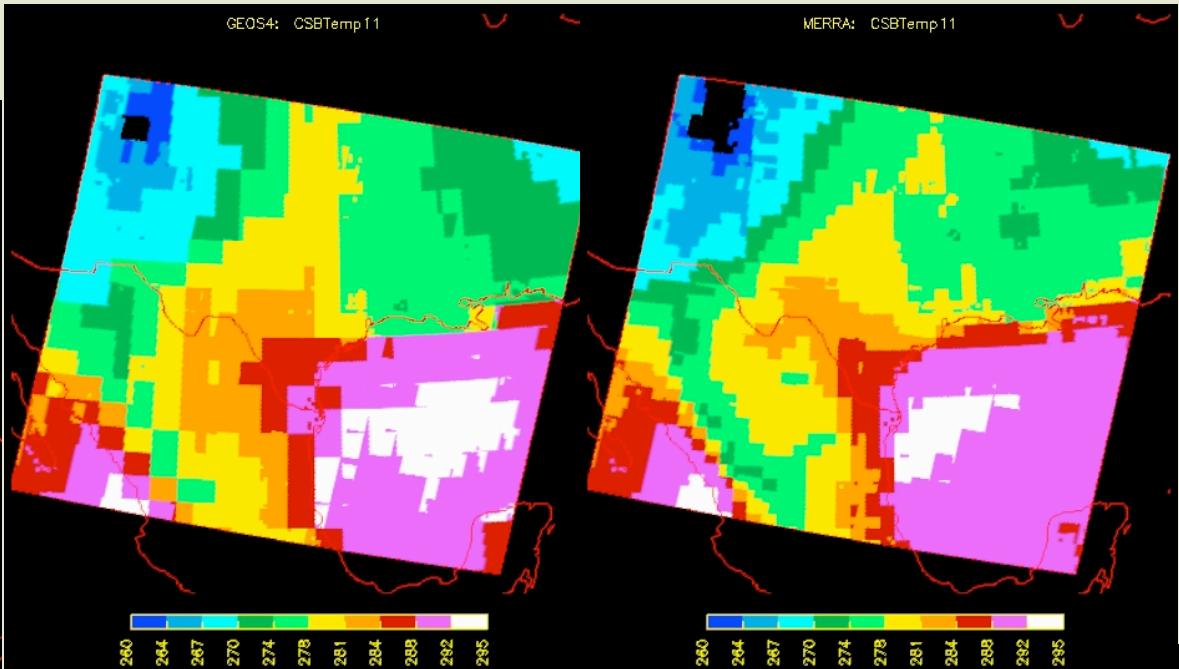


GEOS4 and MERRA Comparison, Aqua MODIS, Jan 27, UTC 06

GEOS-4



Merra



GEOS-4 vs MERRA

- Initial runs made using GEOS-5 & various Merra editions
 - not any huge differences but some, especially in polar night
- Final assessment with final Merra



CERES cloud-related papers published/accepted/submitted since last STM

- Chiriaco, M., et al., 2007: Comparison of CALIPSO-like, LaRC, and MODIS retrievals of ice cloud properties over SIRTA in France and Florida during CRYSTAL-FACE. *J. Appl. Meteorol. Climatol.*, **46**, 249-272.
- Lin, B., K. Xu, P. Minnis, B. A. Wielicki, Y. Hu, L. Chambers, A. Fan, and W. Sun, 2007: Coincident occurrences of tropical individual cirrus clouds and deep convective systems derived from TRMM observations. *Geophys. Res. Lett.*, **34**, L14804, doi:10.1029/2007GL029768.
- Hu, Y., M. Vaughan, C. McClain, M. Behrenfeld, H. Maring, D. Anderson, S. Sun-Mack, D. Flittner, J. Huang, B. Wielicki, P. Minnis, C. Weimer, C. Trepte, and R. Kuehn, 2007: Global statistics of liquid water content and effective number concentration of water clouds over ocean derived from combined CALIPSO and MODIS measurements. *Atmos. Chem., & Phys.*, **7**, 3353-3359.
- Minnis, P., D. R. Doelling, L. Nguyen, and W. F. Miller, 2007: Assessment of the visible channel calibrations of the TRMM VIRS and MODIS on *Aqua* and *Terra*. In press, *J. Atmos. Oceanic Technol.*.
- Yang, P., G. W. Kattawar, G. Hong, P. Minnis, and Y. X. Hu, 2007: Uncertainties associated with the surface texture of ice particles in satellite-based retrieval of cirrus clouds: Part I. Single-scattering properties of ice crystals with surface roughness. *IEEE Trans. Geosci. Remote Sens.*, Accepted.
- Yang, P., G. W. Kattawar, G. Hong, P. Minnis, and Y. X. Hu, 2007: Uncertainties associated with the surface texture of ice particles in satellite-based retrieval of cirrus clouds: Part II. Effect of particle surface roughness on retrieved cloud optical thickness and effective particle size. *IEEE Trans. Geosci. Remote Sens.*, Accepted.
- Dong, X., P. Minnis, B. Xi, S. Sun-Mack, and Y. Chen, 2007: Comparison of CERES-MODIS stratus cloud properties with ground-based measurements at the DOE ARM Southern Great Plains site. Accepted, *J. Geophys. Res.*, 10.1029/2007JD008438.
- Su, J., J. Huang, Quang Fu, P. Minnis, J. Ge, and J. Bi, 2007: Estimation of Asian dust aerosol effect on radiation forcing using Fu-Liou radiative model and CERES measurements. Submitted to *Atmos. Chem. and Phys.*.



CERES cloud-related papers in preparation; to be submitted en masse

- Minnis, P., Q. Z. Trepte, S. Sun-Mack, Y. Chen, D. R. Doelling, D. F. Young, D. A. Spangenberg, W. F. Miller, B. A. Wielicki, R. R. Brown, S. C. Gibson, and E. B. Geier, 2007: Cloud detection in non-polar areas for CERES using TRMM VIRS and Terra and Aqua MODIS data. Ready for submission to *IEEE Trans. Geosci. Remote Sens.*.
- Trepte, Q. Z, P. Minnis, D. A. Spangenberg, R. F. Arduini, S. Sun-Mack, and Y. Chen, “Polar cloud and snow discrimination for CERES using MODIS data,” *IEEE Trans. Geosci. Remote Sens.*, submitted, 2007.
- Minnis, P., Sunny Sun-Mack, and Y. Chen, 2007: Comparison of cloud amounts derived from CERES-MODIS retrievals and the IceSat Geoscience Laser Altimetry System, October 2003. Draft, *Geophys. Res. Lett.*
- Sun-Mack, P. Minnis, Y. Chen, R. F. Arduini, and D. F. Young, “Visible clear-sky and near-infrared surface albedos derived from VIRS and MODIS data for CERES,” *IEEE Trans. Geosci. Remote Sens.*, submitted, 2007.
- Minnis, P., S. Sun-Mack, D. F. Young, P. W. Heck, D. P. Garber, Y. Chen, D. A. Spangenberg, B. A. Wielicki, and E. B. Geier, “Cloud property retrievals for CERES using TRMM VIRS and Terra and Aqua MODIS data,” *IEEE Trans. Geosci. Remote Sens.*, submitted, 2007.
- Minnis, P., Sunny Sun-Mack, and Y. Chen, 2007: Comparison of cloud heights derived from CERES-MODIS retrievals and the IceSat Geoscience Laser Altimetry System, October 2003. In preparation, *Geophys. Res. Lett.*



CALIBRATION

- Paper in press for JTECH on visible channel calibrations
 - Ed3 =>
 - VIRS V6 will have a 1%/y gain correction
 - Terra will have a 1.17% discontinuity correction in Nov 2003
 - Terra 1% less than Aqua, Ed3 needs to decide which is reference & adjust one or the other
 - Mask paper shows
 - Terra 3.7- μ m warmer than Aqua by 0.5K for T > 240K
 - Terra 3.7- μ m minimum at 220 K, needs correction to Aqua
 - VIRS 1.6- μ m gain needs correction of 1.19 vs. Ed2 1.17
- Ed3 => correct Terra 3.8 μ m and VIRS 1.6 μ m



VALIDATION

- Paper accepted by JGR on stratus val at ARM SGP
 - height underestimated by 300- 500 m
 - soundings would give larger overestimate w/ larger RMS
 - Terra re, tau, and LWP very close on average
 - Aqua re within $0.3 \mu\text{m}$ on average
 - tau & LWP large by 25%

=>

- $-5.5^\circ/\text{km}$ lapse rate would yield unbiased heights, same RMS
 - => need more stats to set lapse rates, CALIPSO?
- adjust Aqua VIS channel?



Objectives

- Use CALIPSO and CloudSat data products to
 - assess errors in CERES-MODIS cloud properties
 - *cloud fraction, top/base heights, thickness*
 - develop improved algorithms for CERES Edition 3 clouds
 - only focus on mask, heights, & thickness
 - optical depth data just becoming available



CERES-MODIS Cloud Retrieval Methodology

(Apply CERES algorithms to MODIS imager data)

1) Apply cloud mask

see Minnis et al. (2007a), Trepte et al. (2007)

2) Compute ice & water phase solution, select most likely phase based on temperature, model fits, LBTM classification, 2.1- μm reflectance

DAY: Visible Infrared Solar-Infrared Split-Window Technique (VISST)

0.65, 3.8, 10.8, & 12.0 μm

see Minnis et al. (1995, 1998, 2007b)

NIGHT: Solar-infrared Infrared Split-Window Technique (SIST)

3.8, 10.8, & 12.0 μm

see Minnis et al. (1995, 1998, 2007b)

SNOW (DAY): Solar-Infrared Infrared Near-Infrared Technique (SINT)

2.1, 3.8, 10.8, & 12.0 μm

see Platnick (JGR, 2001), Minnis et al. (2007b)



CERES Cloud-top Height Estimation

Observed 11- μm radiance:

$$L = (1 - \epsilon) L_s + \epsilon L_{\text{eff}}$$

Corresponding effective cloud temperature:

$$T_{\text{eff}} = B^{-1}(L_{\text{eff}})$$

For high clouds:

$$Z_{\text{eff}} = Z(T_{\text{eff}})$$

$Z(T)$ - sounding from GEOS 4.03

For low clouds:

$$Z_{\text{eff}} = (T_{\text{eff}} - T_o) / \Gamma + Z_o$$

Z_o = surface height above sea level, T_o = skin temp , $\Gamma = -7.1\text{K/km}$

is adjusted between 700 & 500 hPa so that $T_{500} = T_{500}(\text{GEOS 4})$

(Minnis et al., JAM, 1992; TGARS, 2007)

For optically thick & water clouds,

$$Z_{\text{top}} = Z_{\text{eff}}$$

For optically thin ice clouds,

$$Z_{\text{top}} = Z(T_{\text{eff}}, \tau)$$

(Minnis et al., JAS, 1991)



CERES Cloud-base Height Estimation

Cloud thickness:

$$\Delta Z = f(\text{phase}, T_{\text{eff}}, \tau)$$

based on surface & aircraft radar/lidar data

Cloud base Height:

$$Z_{\text{base}} = Z_{\text{top}} - \Delta Z$$

Constraint:

$$Z_{\text{base}} > Z_o$$

(Minnis et al., JAM 1992, TGARS, 2007; Chakrapani, ARM 2002)



DATA

Aqua - MODIS:

Data Products Used: L1: MAC02 (radiance), L1:MAC03 (geolocation) and L2; MAC04 (aerosol).

Full resolution (1 km) with 22 bands subset: 201 km MODIS swath centered at the CloudSat nadir track.

CALIPSO:

Data Product Used: Vertical Feature Mask (VFM).

Altitude Region(km)	Vertical Res (m)	Horizontal Res (m)
-0.5 - 8.2	30	333
8.2 - 20.2	60	1000
20.2 - 30.1	180	1667

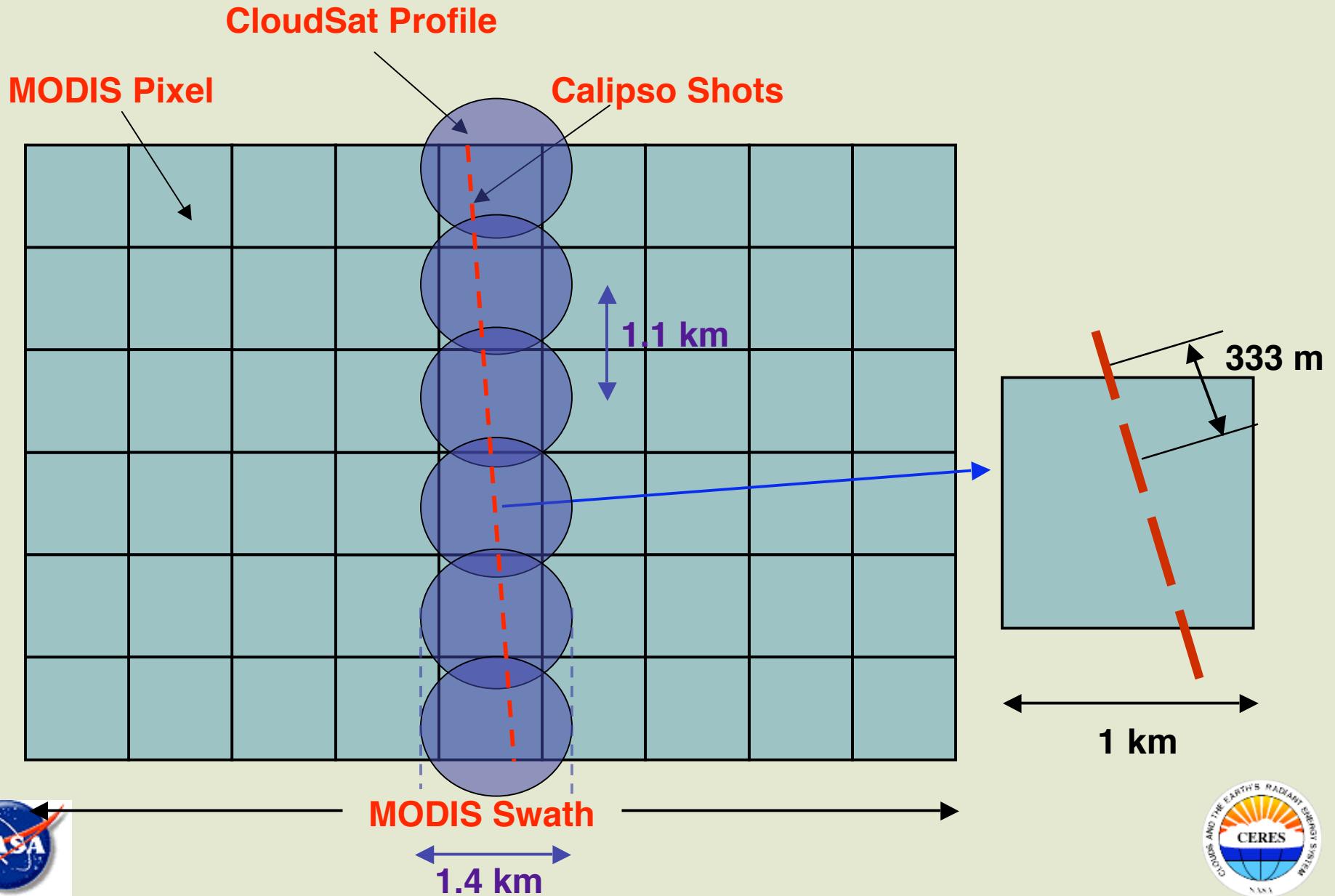
CloudSat:

Data Product Used: Cloud Scenario Classification (CLDCLASS):

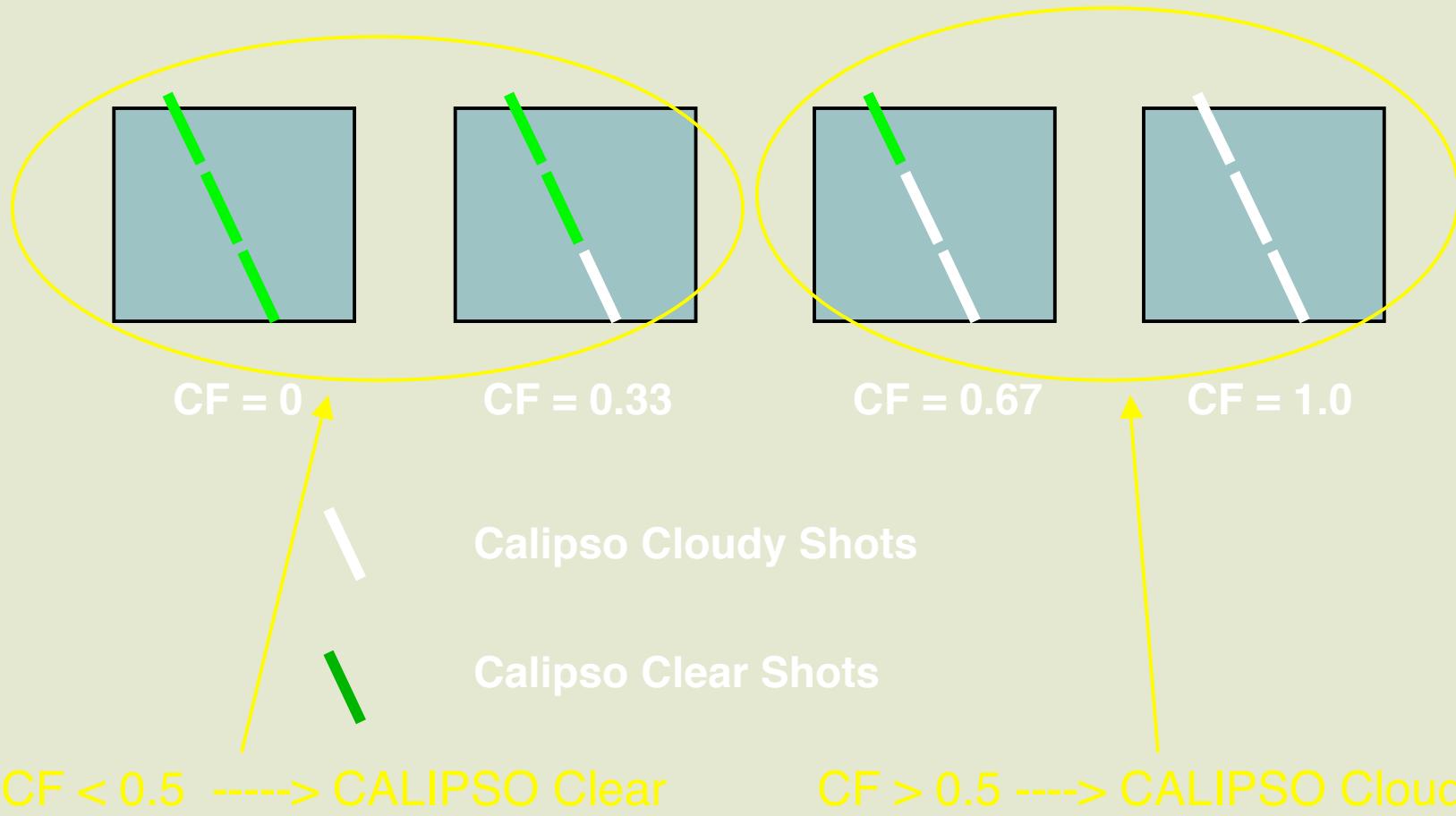
Altitude Region(km)	Vertical Res (m)	Horizontal Res (km)
0 - 25	240	1.1 x 1.4



MODIS, Calipso and CloudSat Collocation Match Up.



CALIPSO Cloud Fraction for each 1-km MODIS Pixel



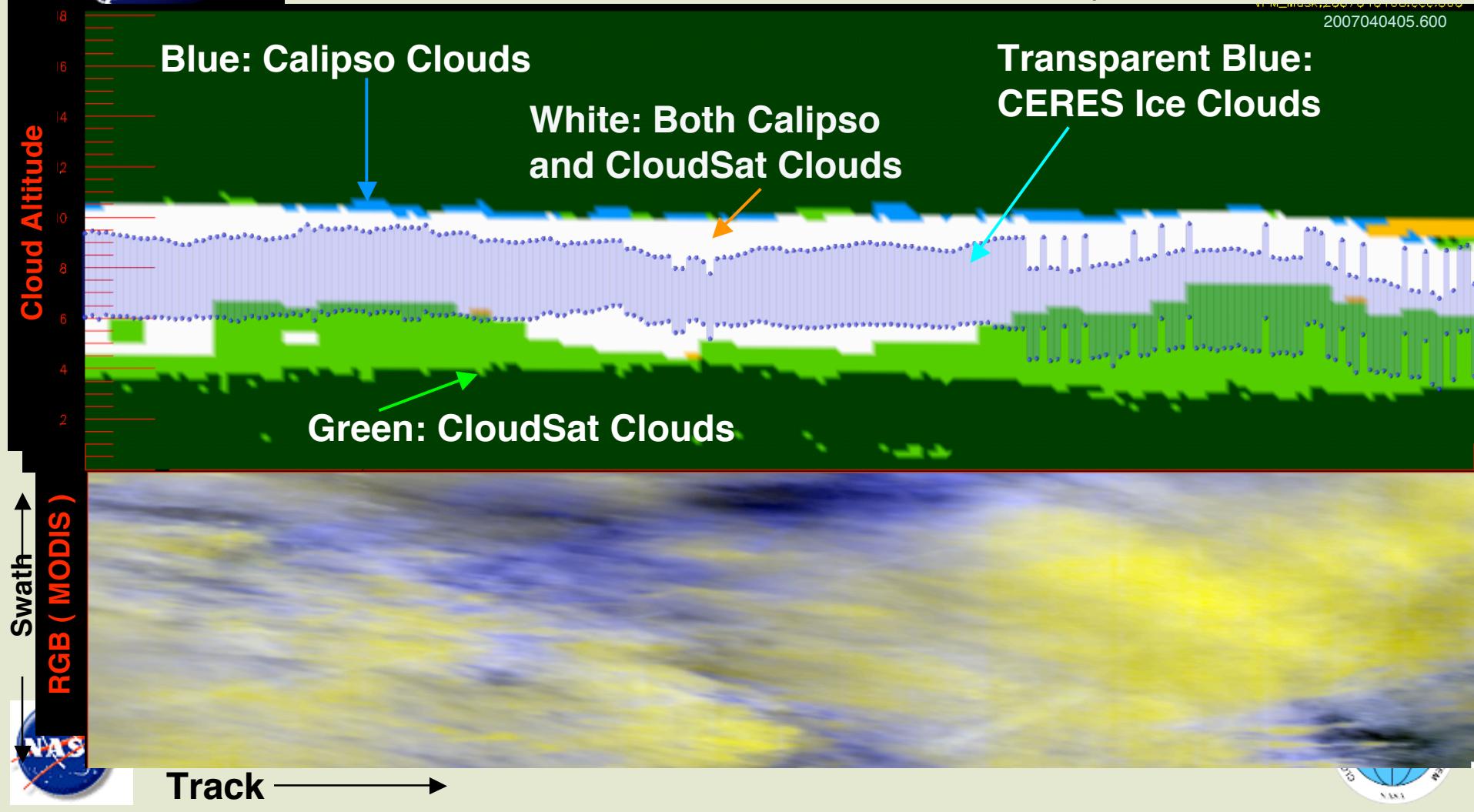
A month of data were successfully merged
and an integrated product was produced





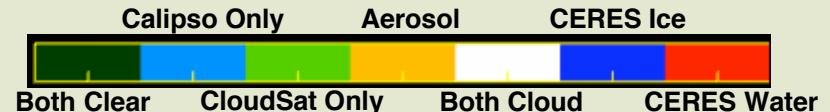
CALIPSO, CloudSat & CERES-MODIS Merged Example 1

4 April 2007, 0500 UTC (200 km Coverage, night)

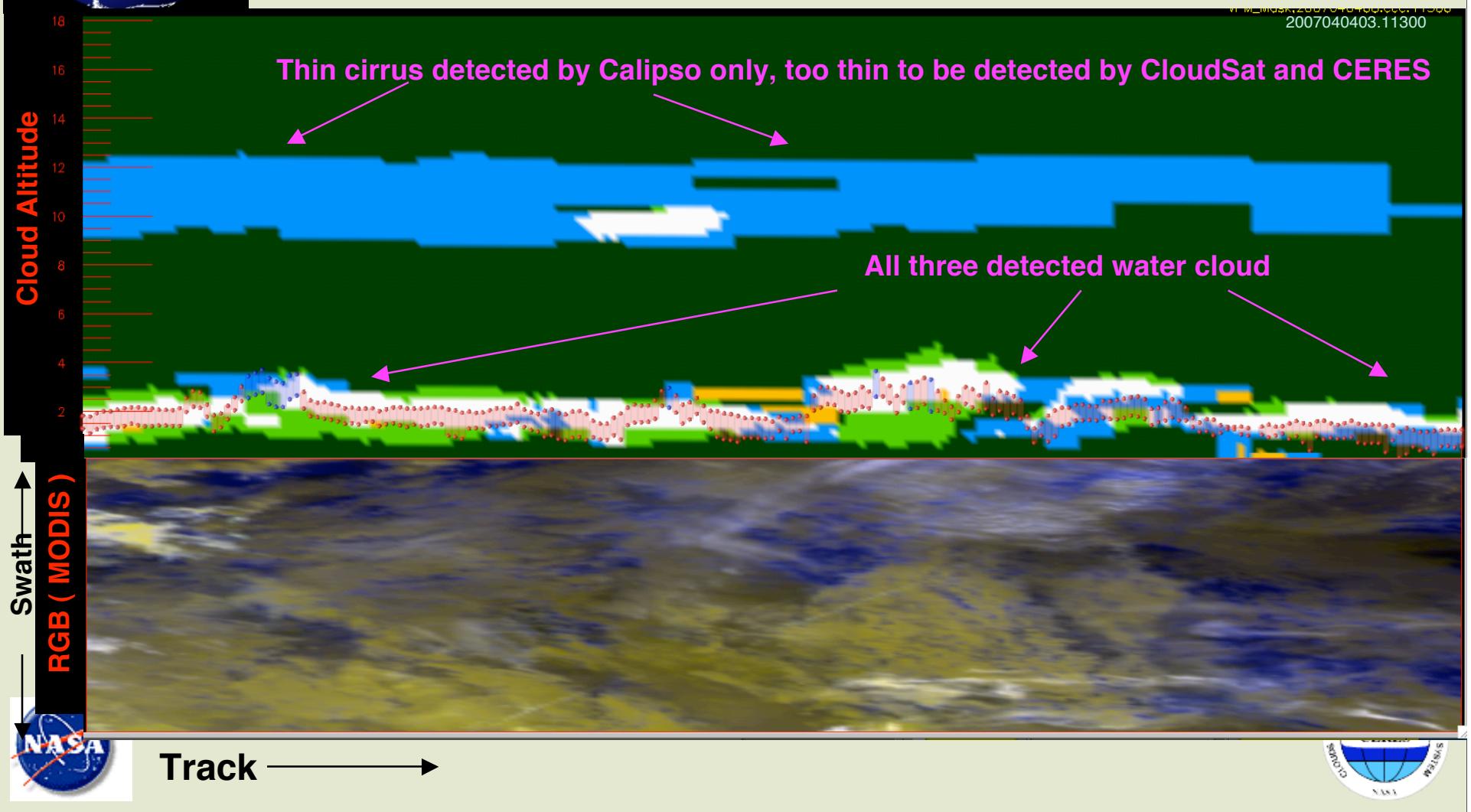


CALIPSO, CloudSat and CERES-MODIS Merged Example 2

4 April 2007, 0300 UTC (200 km Coverage, night)

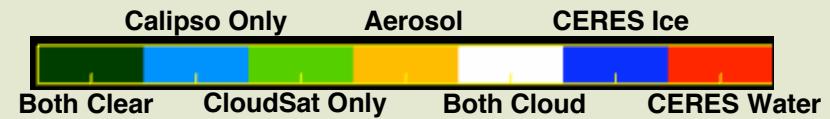


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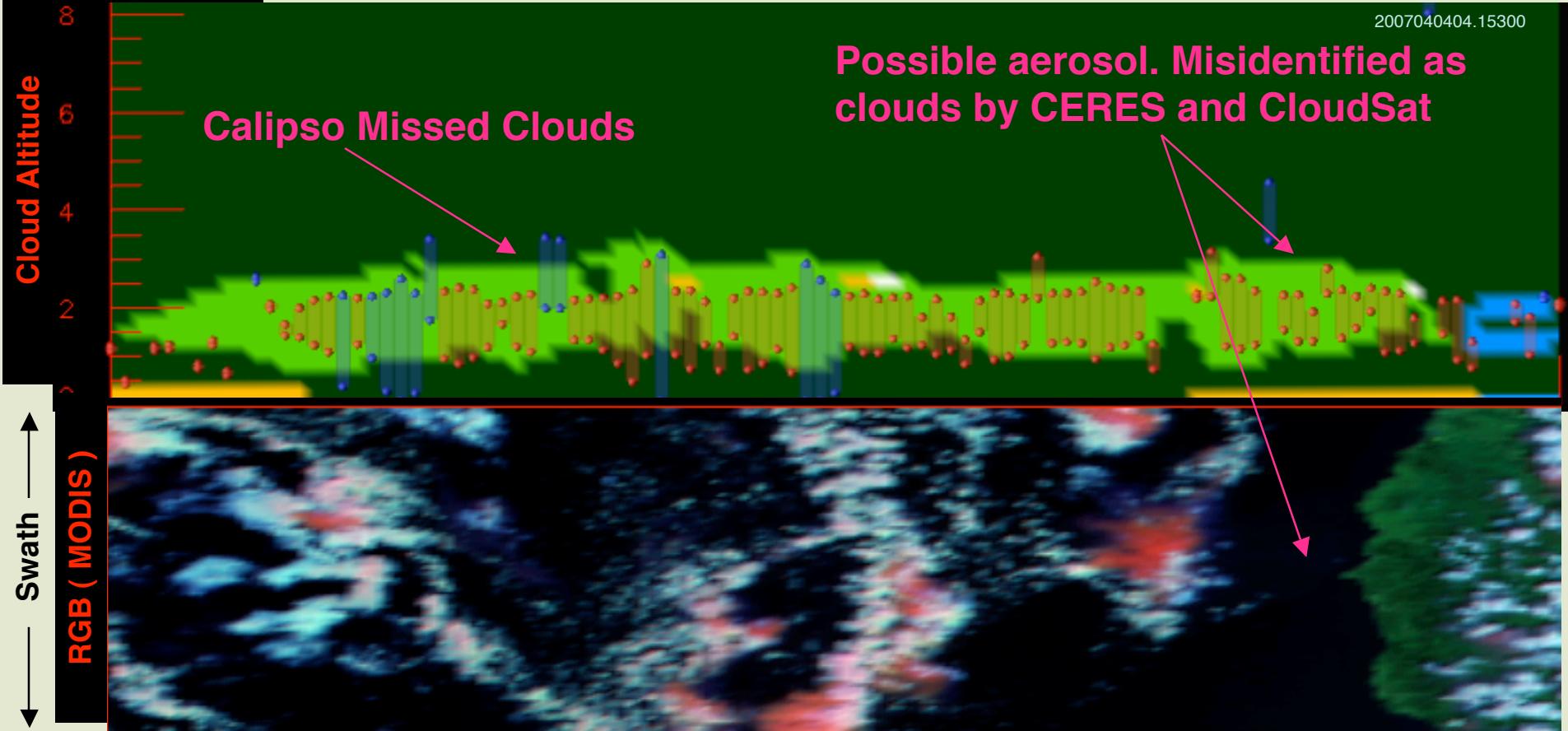


CALIPSO, CloudSat & CERES-MODIS Merged Example 4

4 April 2007, 0400 UTC (100 km Coverage, day)



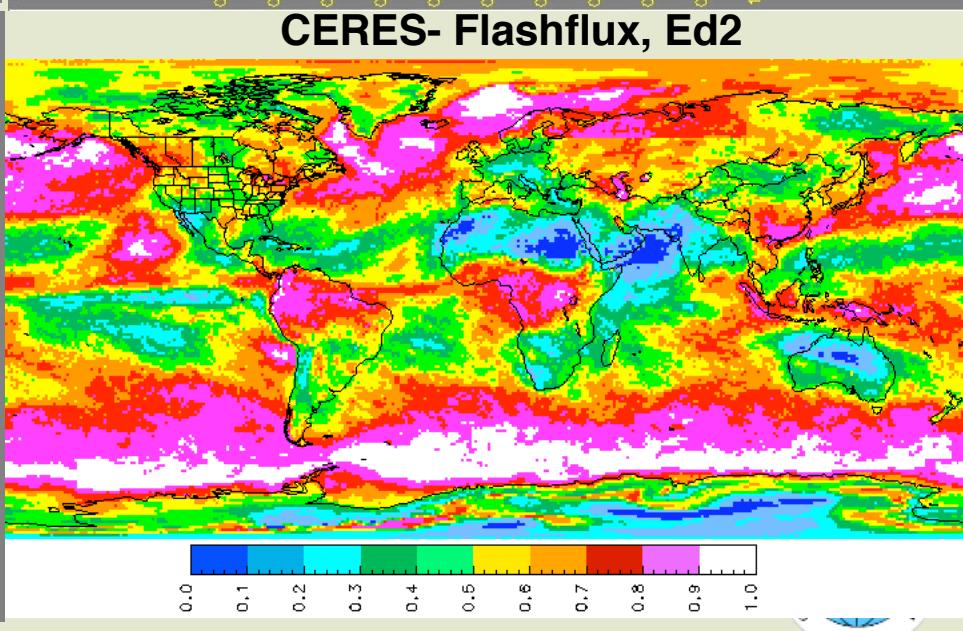
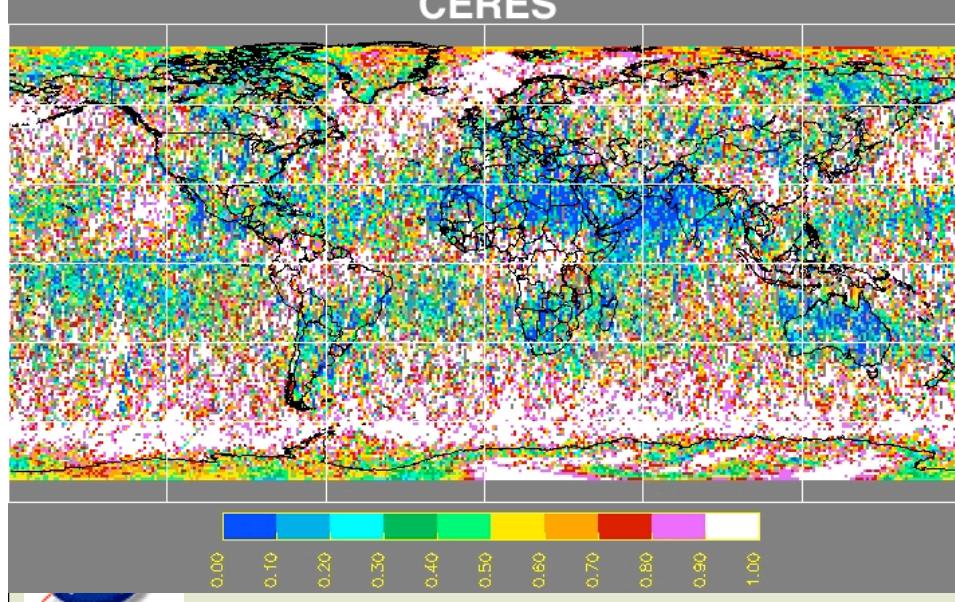
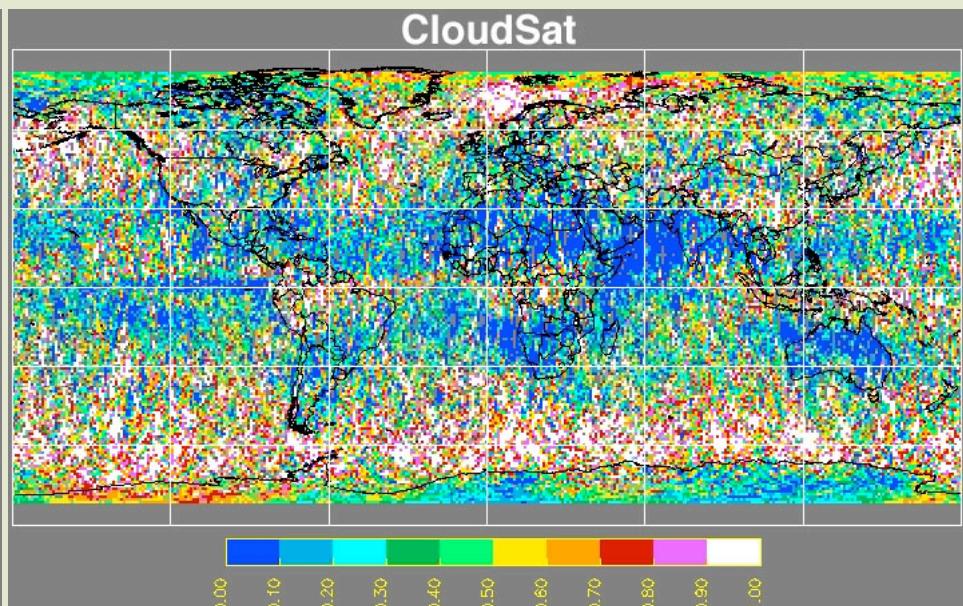
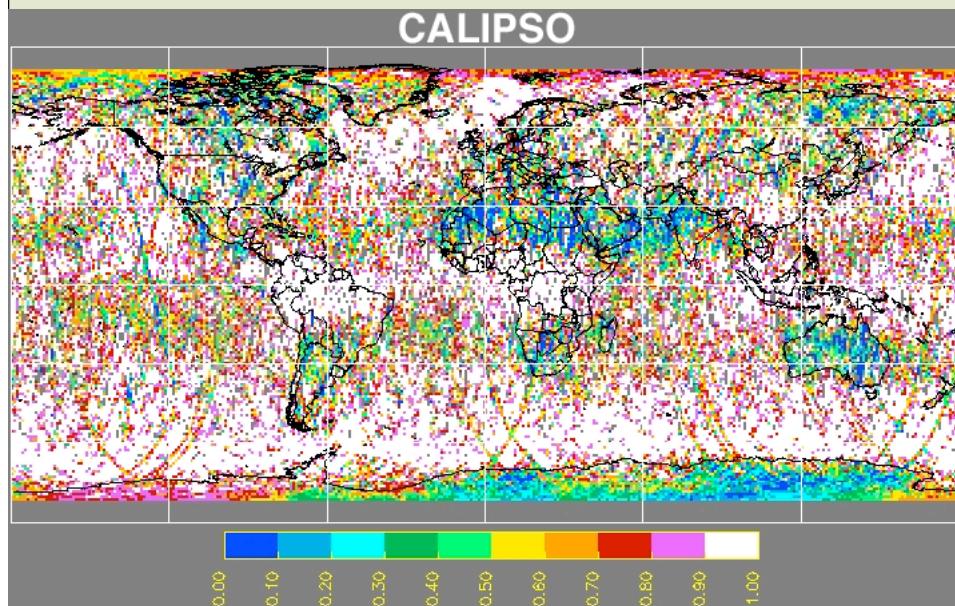
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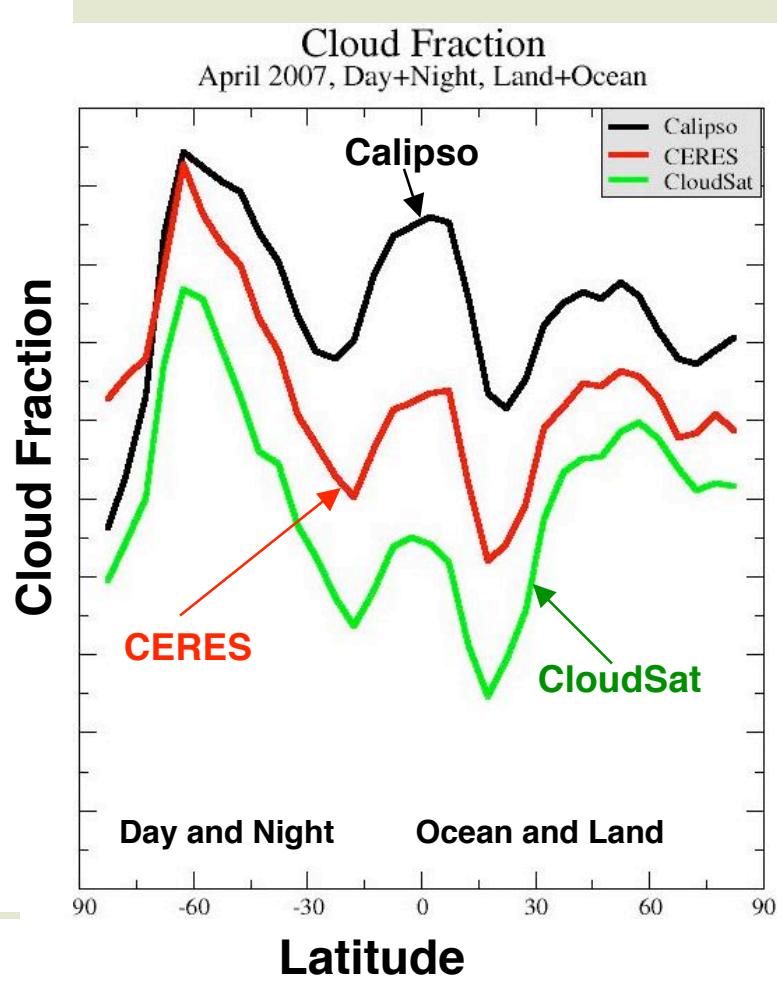
Track →



Mean Cloud Fraction April 2007



Cloud Fraction Inter-Comparisons (April, 2007)



Day Time

	CALIPSO	CERES	CloudSat
Ocean	0.77	0.66	0.47
Land	0.71	0.55	0.43

11%, 19%

16%, 12%

Night Time

	CALIPSO	CERES	CloudSat
Ocean	0.83	0.65	0.51
Land	0.69	0.54	0.43

18%, 14%

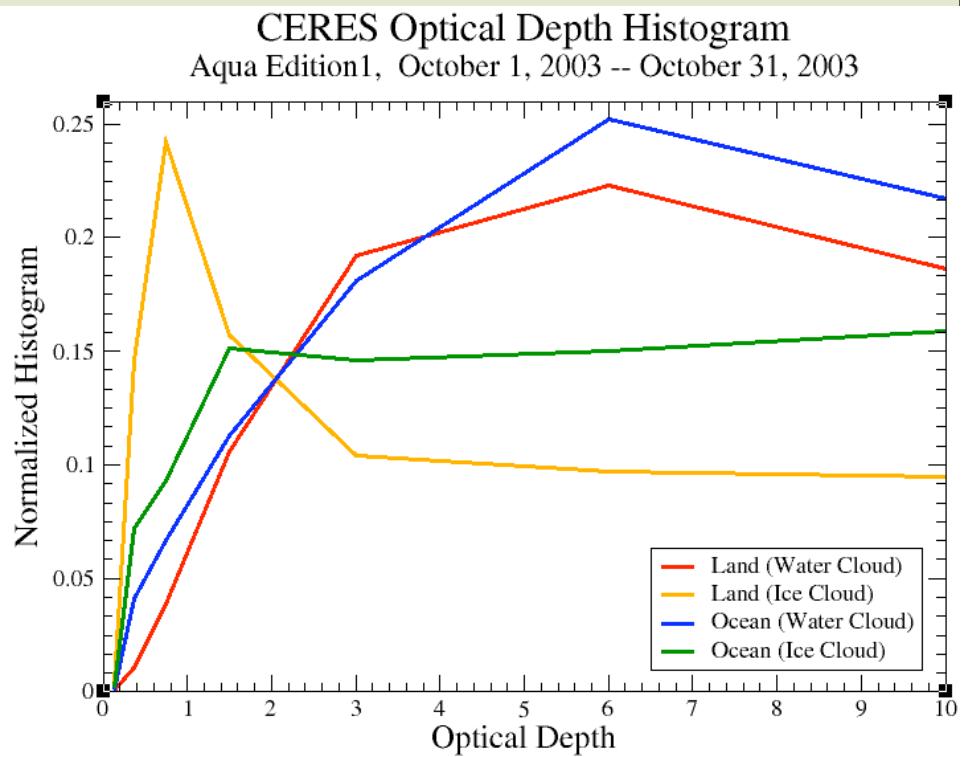
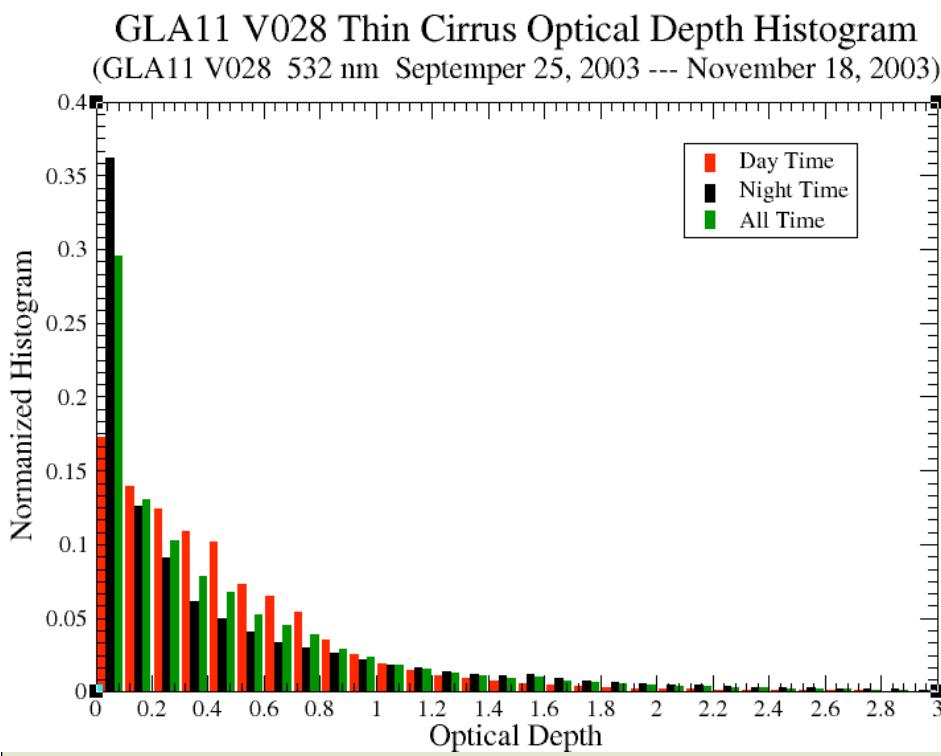
15%, 11%

CERES detects 15% < cloud cover than CALIPSO

- mainly due to low optical depths?



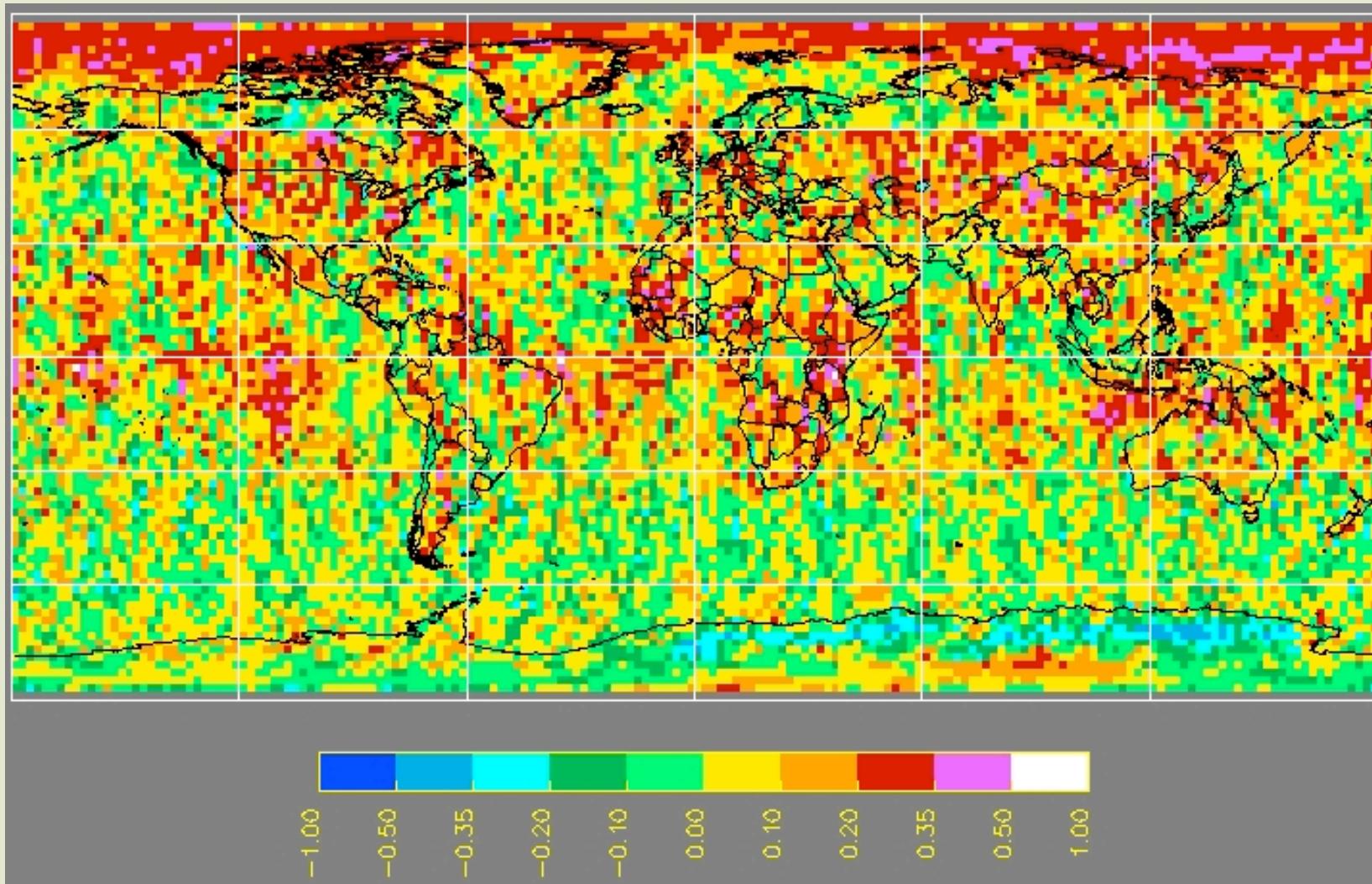
CERES vs GLAS Optical Depths



Suggests CERES shortfall is all optically thin clouds



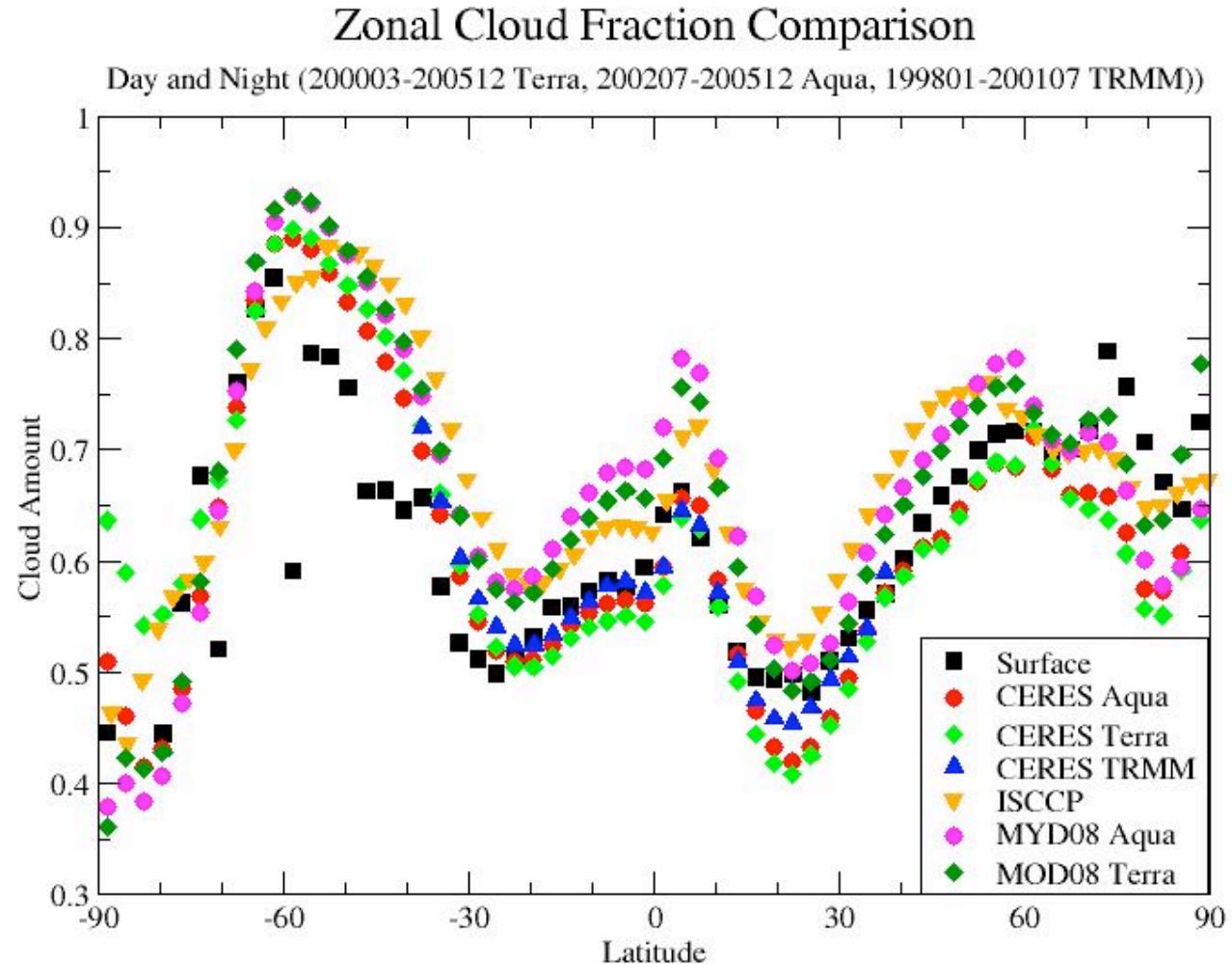
Cloud Amount Difference GLAS-CERES, October 2003



Differences in areas with both low and high cloud cover



Comparisons of Ed2 with other masks

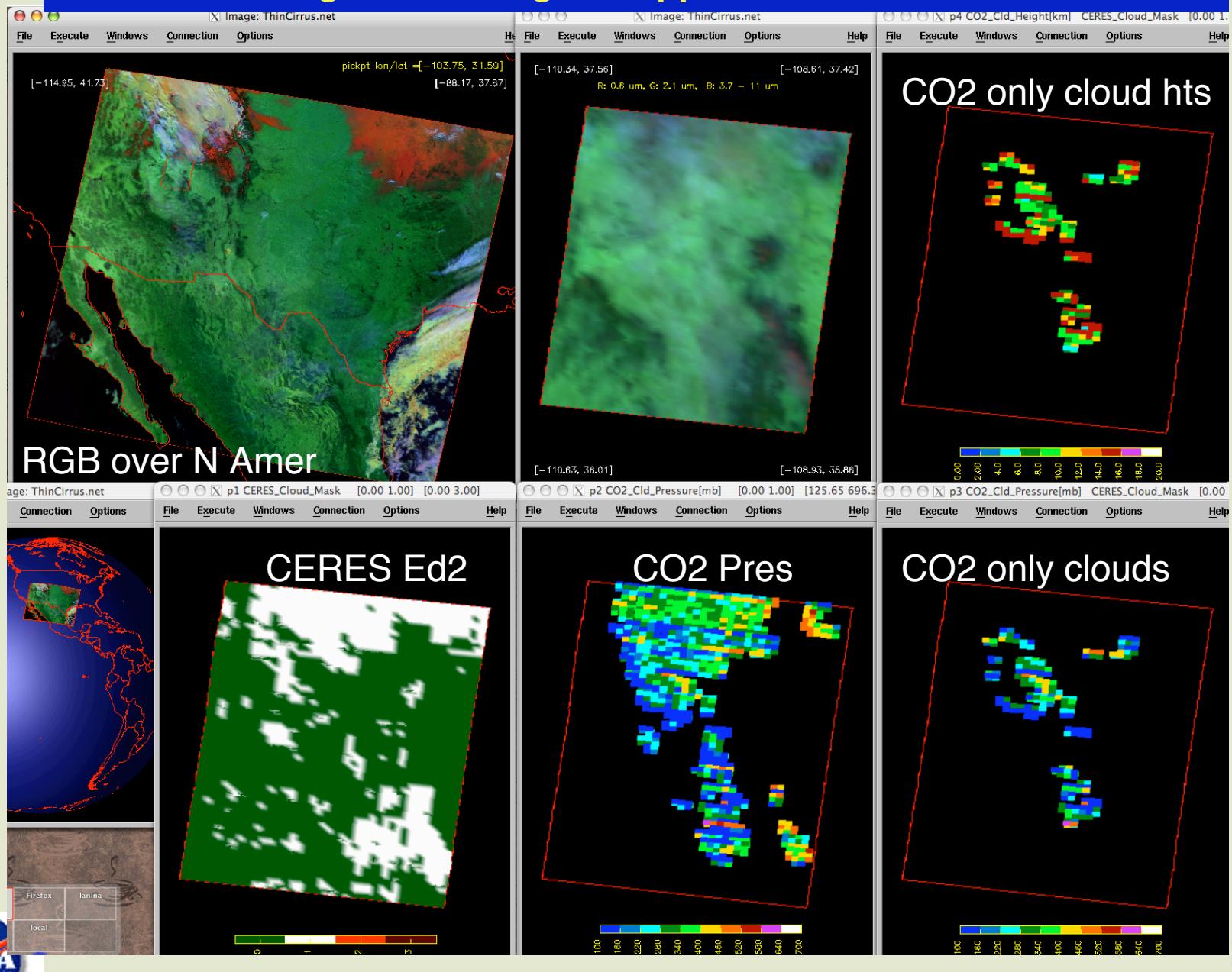


CERES detects fewer clouds than ISCCP or MODIS, not surface

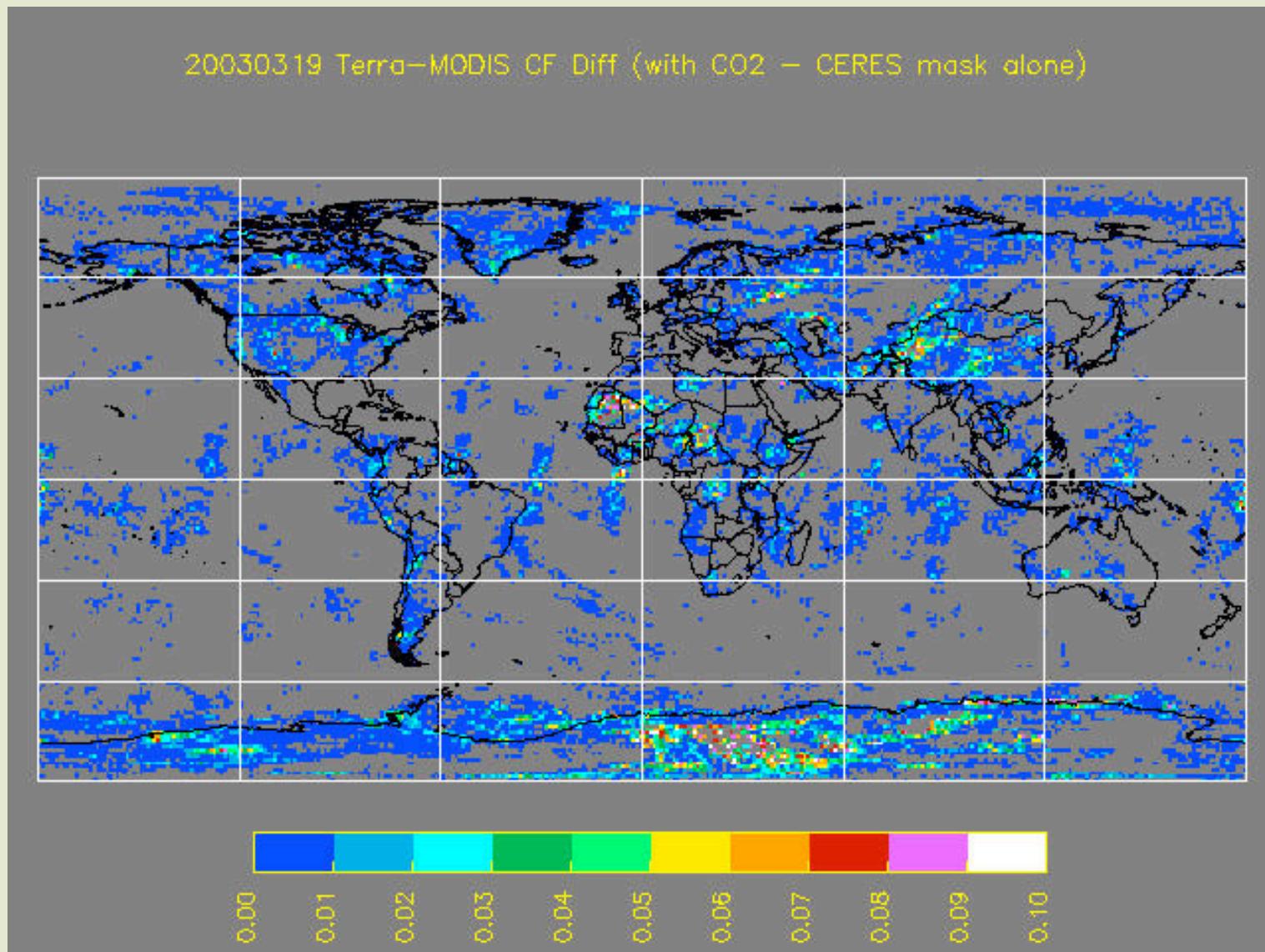
CERES retrieves cloud properties for more clouds than MODIS



Using CO2-slicing to Supplement Cloud Mask



Cloud Amount Changes for 1 day using Current CO₂ Retrieval



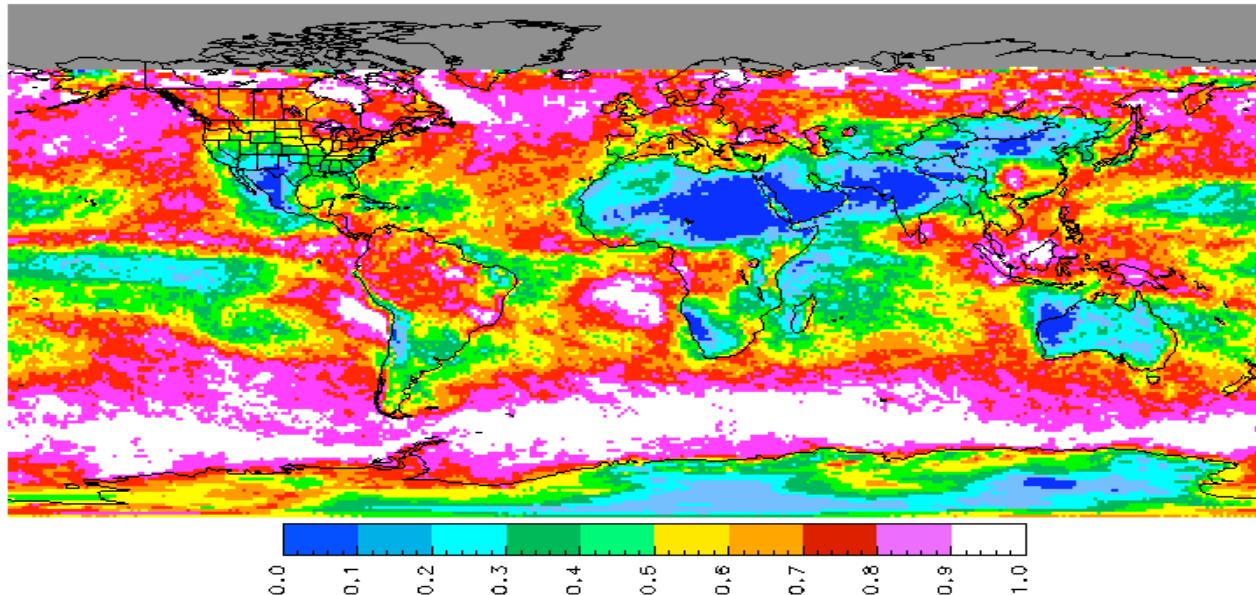
CO₂-slicing Mask

- Using current retrieval formulation: cloud amount increases
 - 1.6% over day desert; 0.5% over night desert
 - 1.7% over Antarctica day & night
 - 0.3% over land
 - negligible over ocean
- New code (from Chang) will produce increases everywhere
 - both thin cirrus and low clouds

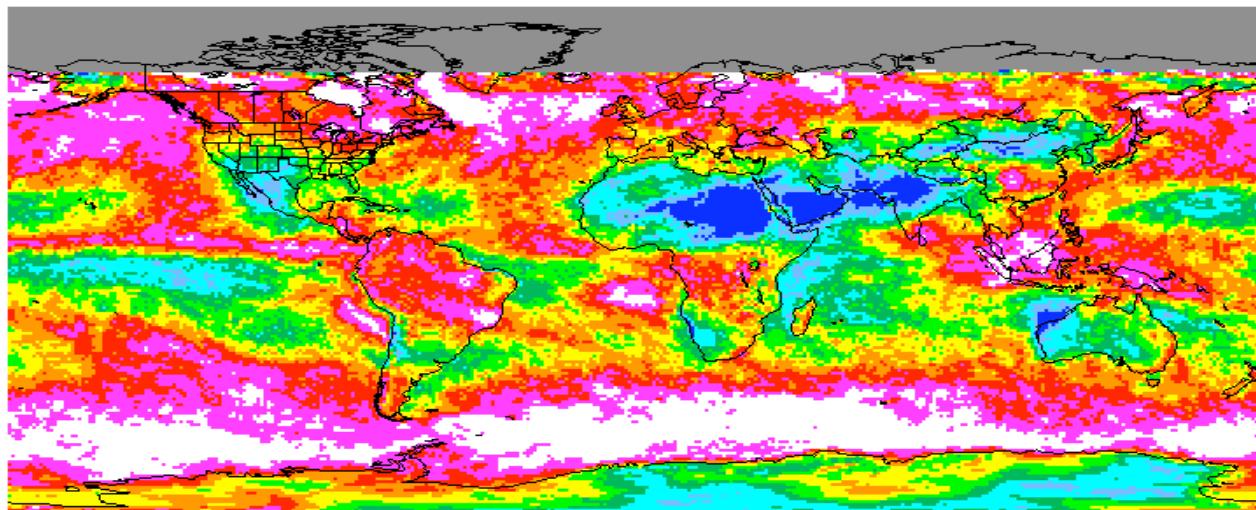


Improvements in Polar-Mask Discontinuity

200511 Terra-MODIS.Edition2-QC CloudFraction-Total Day



200511 Aqua-MODIS.Edition1A CloudFraction-Total Day



Terra shows less discontinuity than
Aqua using new
1.6 models

Aqua 2.1- μ m
thresholds to be
altered and used
with Terra



Mask Changes in Ed3

- a. In Twilight cloud mask:

- # added thin Ci tests over ocean and land, daytime only

- # refined 3.7- μm emissivity-dependent low cloud thresholds.

- b. Improved daytime polar mini-mask for further classify TBD pixels.

- c. Made changes in nighttime polar mask for non-super-cold Plateau.

- d. Modified ocean_aerosol tests.

- e. Improved Sunglint Tests to pick up clouds with low BTD 3.7-11.

- f. Modified C4_land tests to pick up more thin Ci

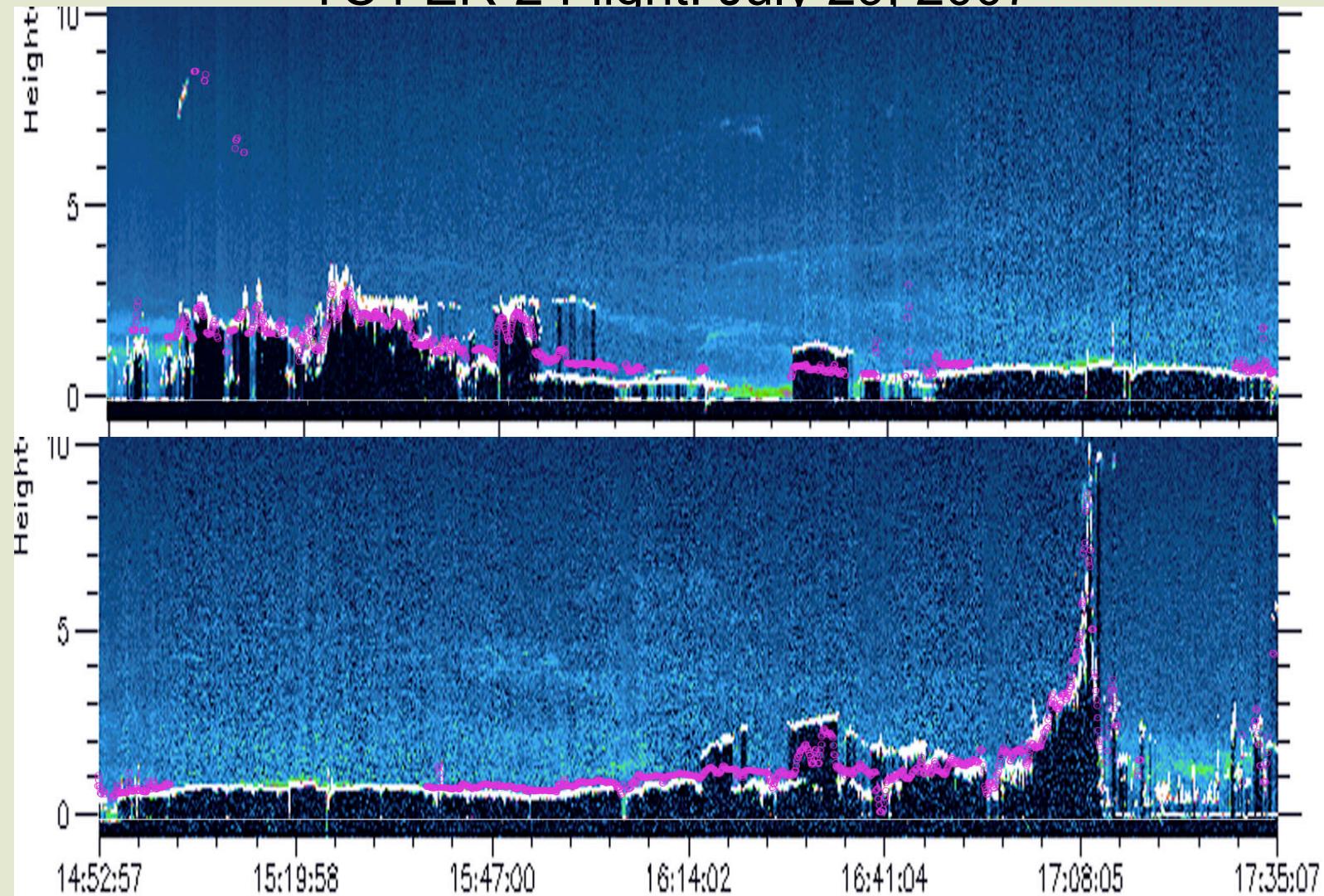
- g. Implemented CO₂-slicing mask

- h. Hi-res VIS data analysis over ocean (Beta 2)



Using Field Program Data for Validating Heights

TC4 ER-2 Flight: July 29, 2007

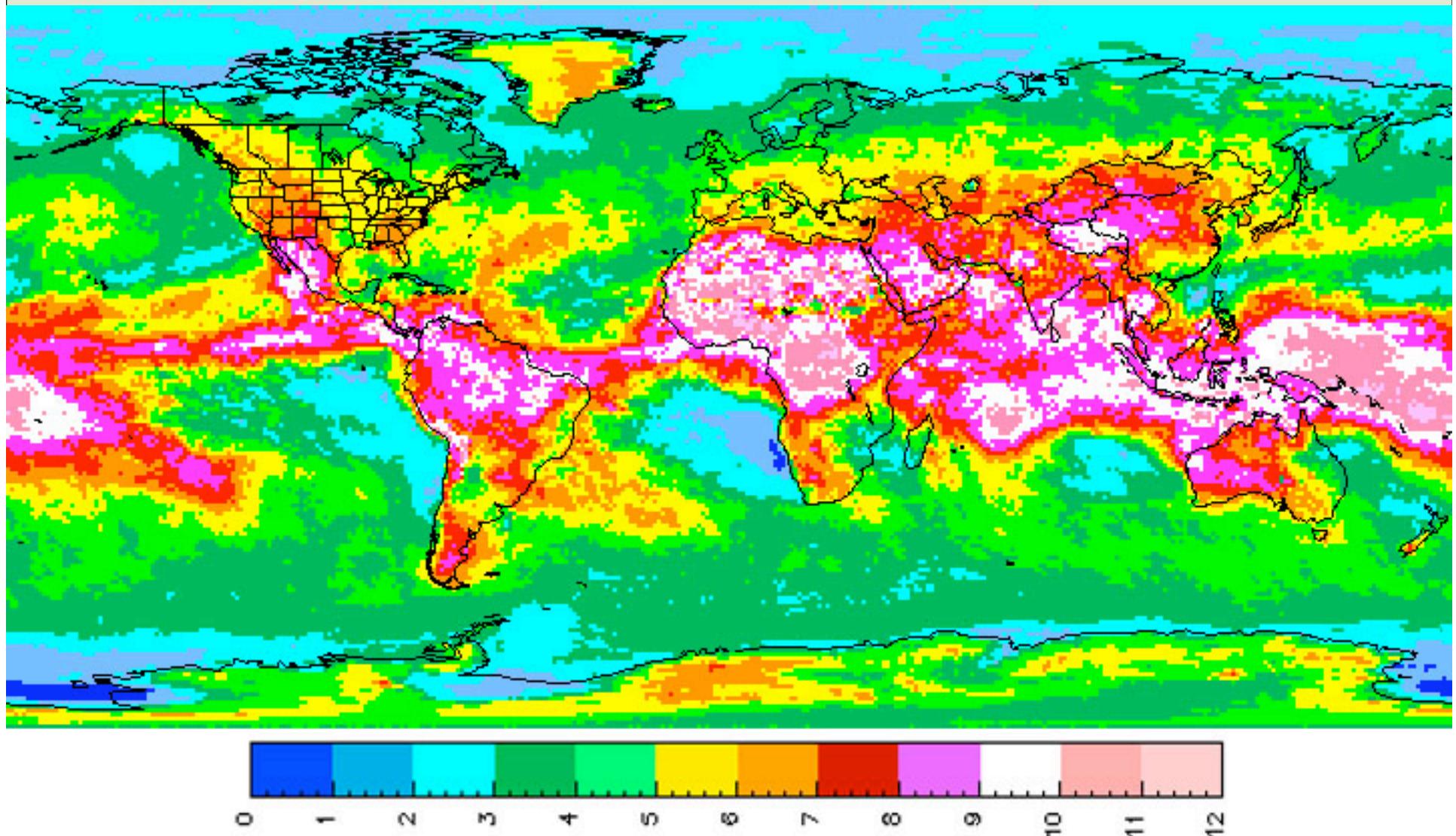


- GOES-derived effective cloud top within a few hundred meters of marine stratus tops



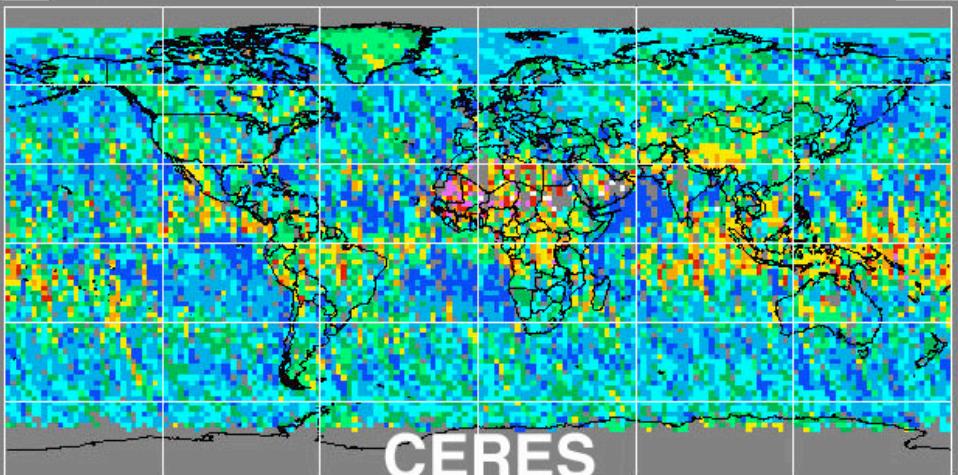
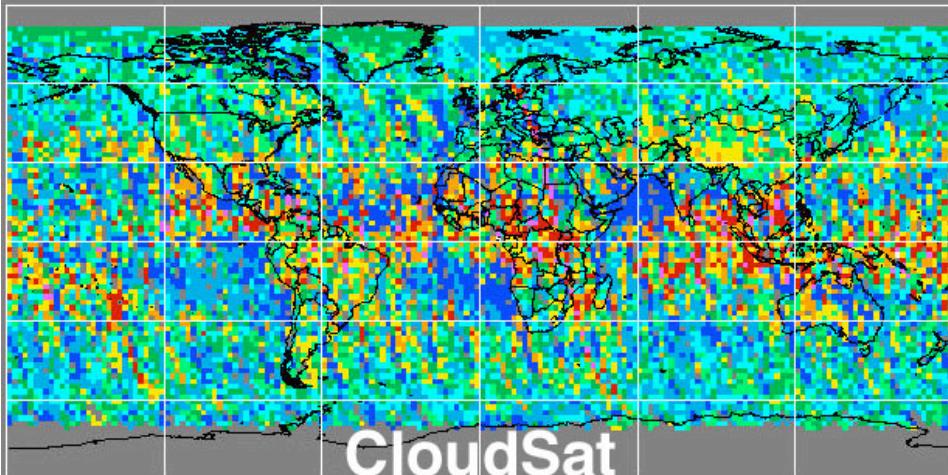
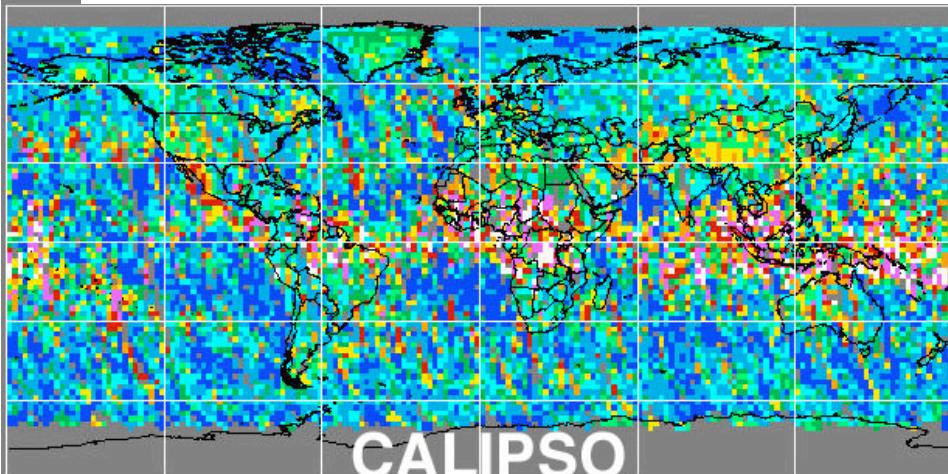
Using CloudSat-CALIPSO Data for Validating Heights

Mean CERES-MODIS Effective Cloud Top Height (km) April 2007



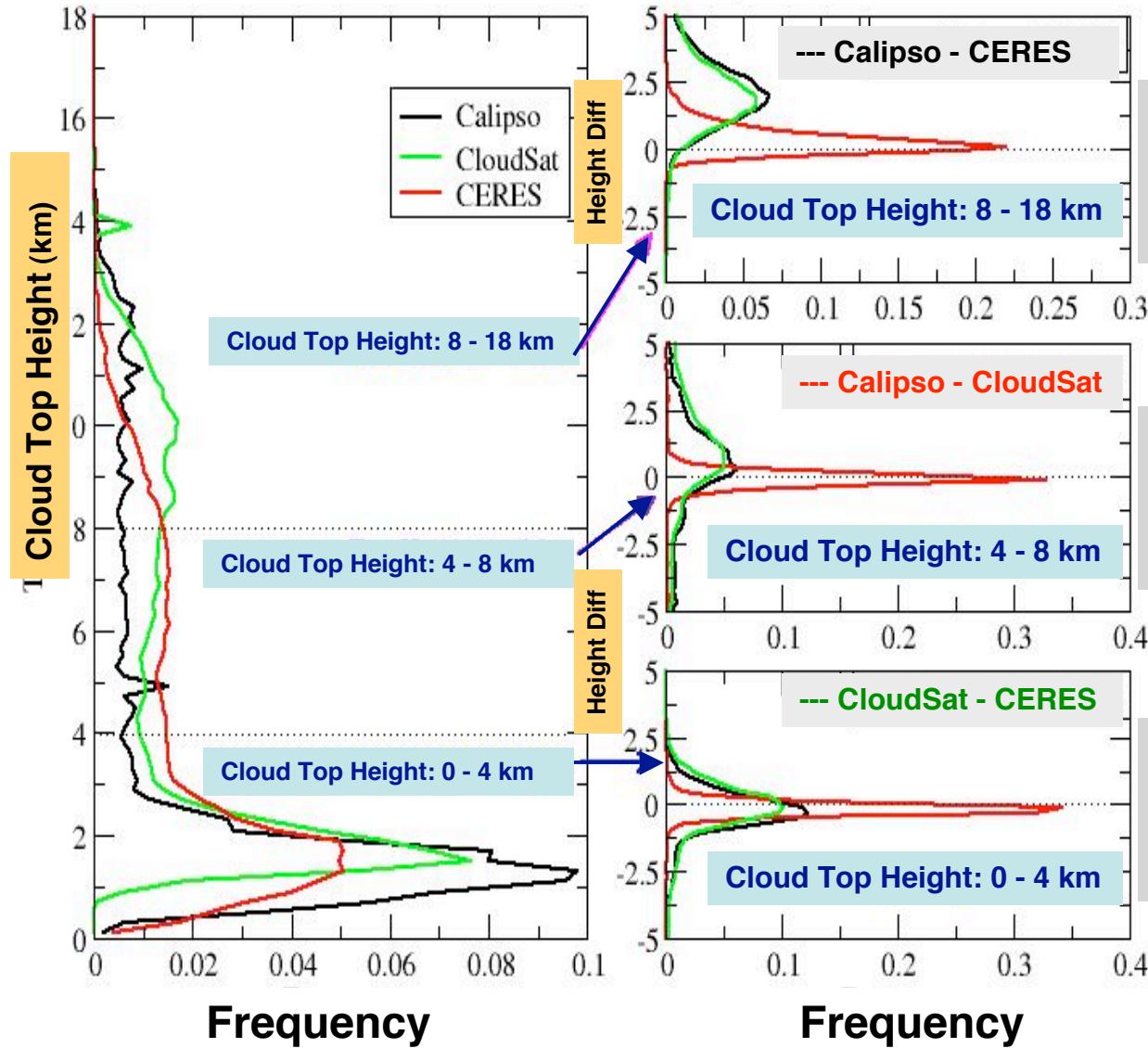
Mean SL Cloud Top Heights (km) Along A-Train Path

Daytime, April 2007



Cloud Top Height Inter-Comparisons (Single Layer)

April 2007, Ocean, DayTime, Mid-latitude
Southern Hemisphere (Lat = -30 --- -60)

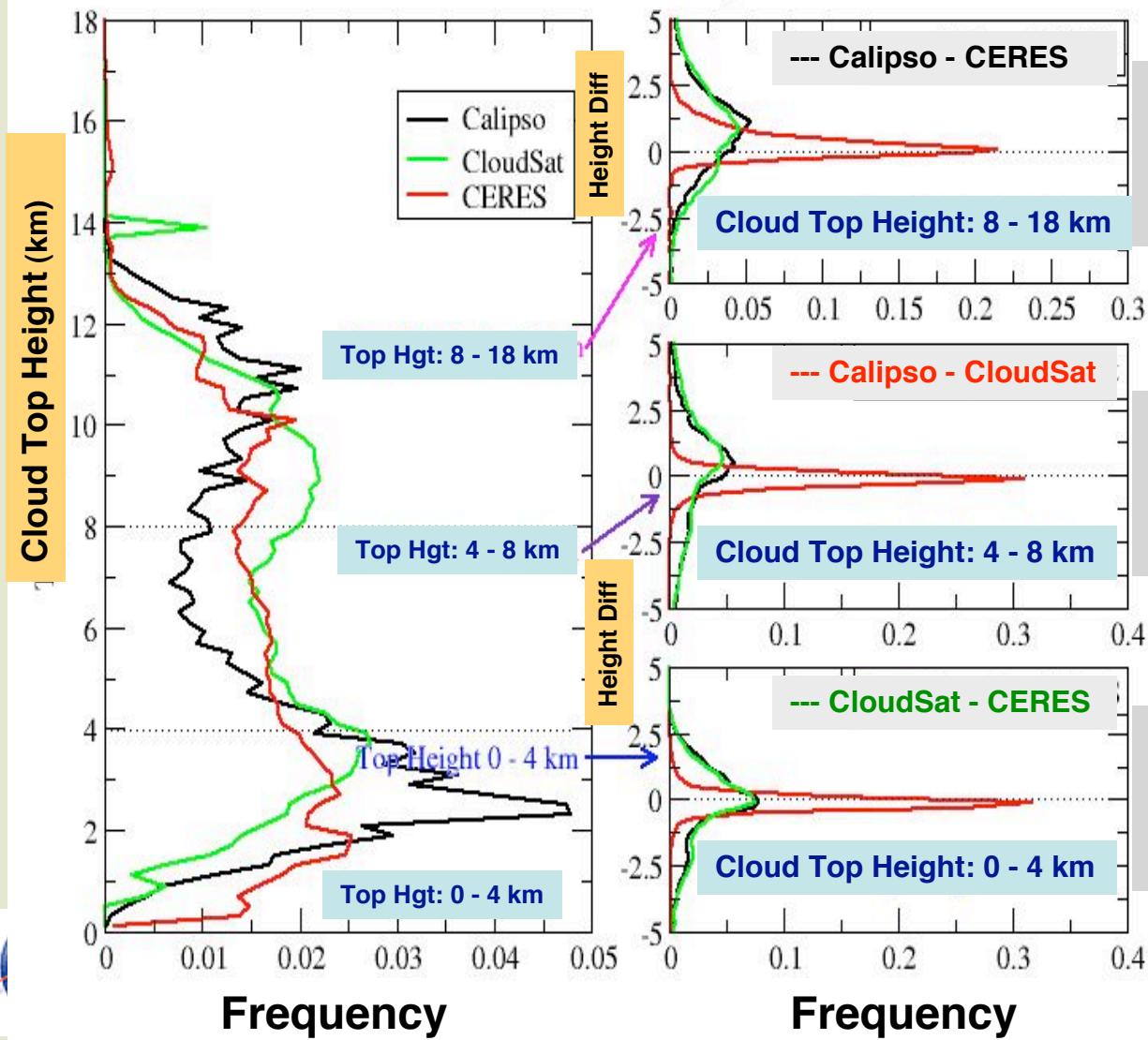


Cloud Top Height Difference: Mean (Bias)

Calipso - CloudSat:	0.34 (1.96) km
Calipso - CERES:	2.4 (11.63) km
CloudSat - CERES:	2.2 (11.85) km
Calipso - CloudSat:	-0.25 (2.25) km
Calipso - CERES:	0.15 (3.58) km
CloudSat - CERES:	0.93 (5.02) km
Calipso - CloudSat:	-0.32 (2.54) km
Calipso - CERES:	-0.51 (4.21) km
CloudSat - CERES:	-0.42 (3.94) km

Cloud Top Height Inter-Comparisons (Single Layer)

April 2007, Land, DayTime, Mid-latitude
Northern Hemisphere (Lat = 30 --- 60)

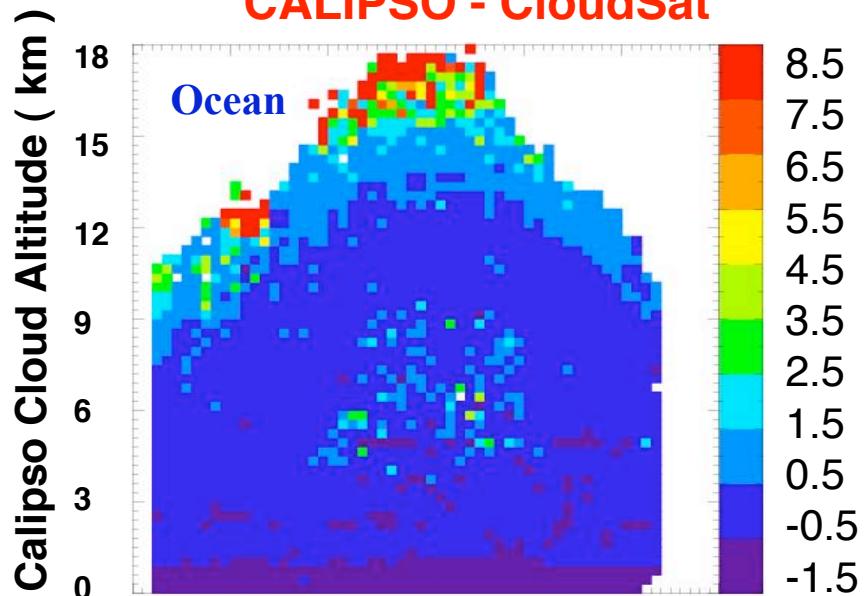


Cloud Top Height Difference: Mean (Bias)

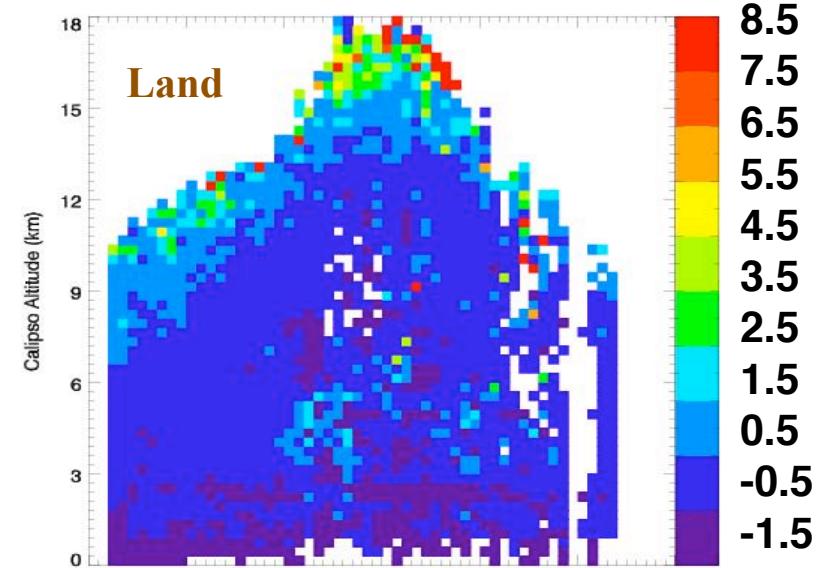
Calipso - CloudSat:	0.50 (1.98) km
Calipso - CERES:	1.62 (5.49) km
CloudSat - CERES:	1.27 (5.04) km
Calipso - CloudSat:	-0.14 (1.14) km
Calipso - CERES:	-0.17 (4.77) km
CloudSat - CERES:	0.20 (4.13) km
Calipso - CloudSat:	-0.42 (3.44) km
Calipso - CERES:	-0.55 (5.75) km
CloudSat - CERES:	-0.58 (5.70) km

Zonal Cloud Top Height Difference (km) versus Cloud Altitude

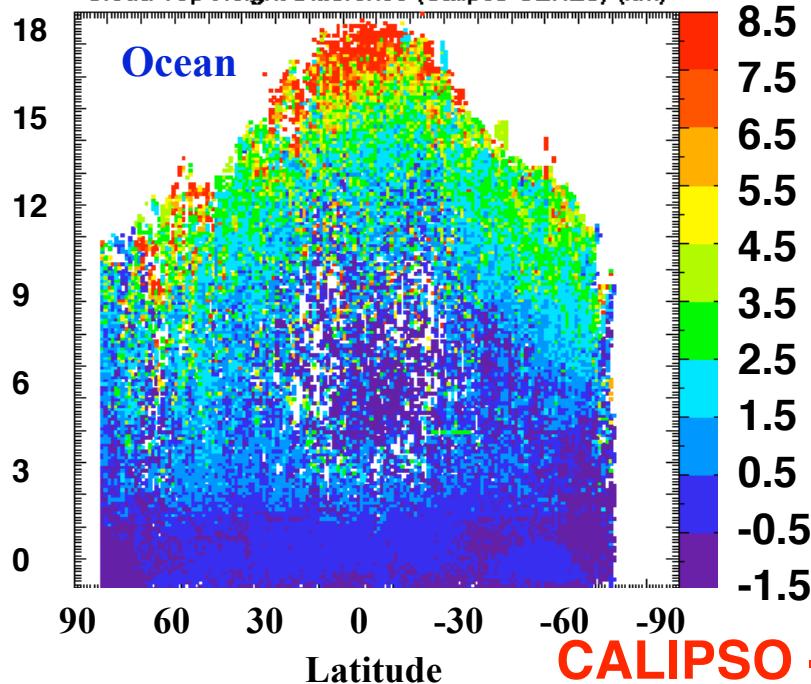
CALIPSO - CloudSat



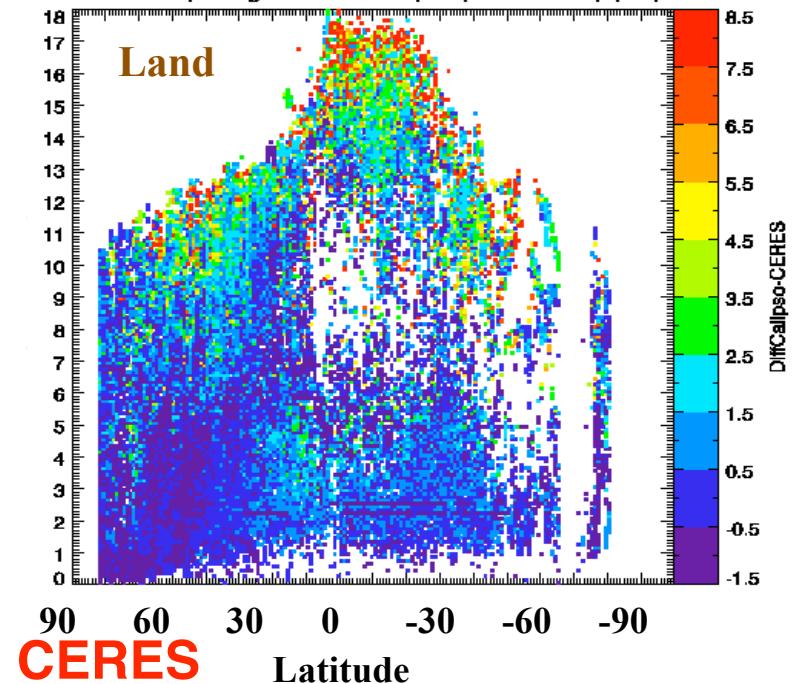
CALIPSO - CloudSat



Cloud Top Height Difference (Calipso-CERES) (km)



Cloud Top Height Difference (Calipso-CERES) (km)

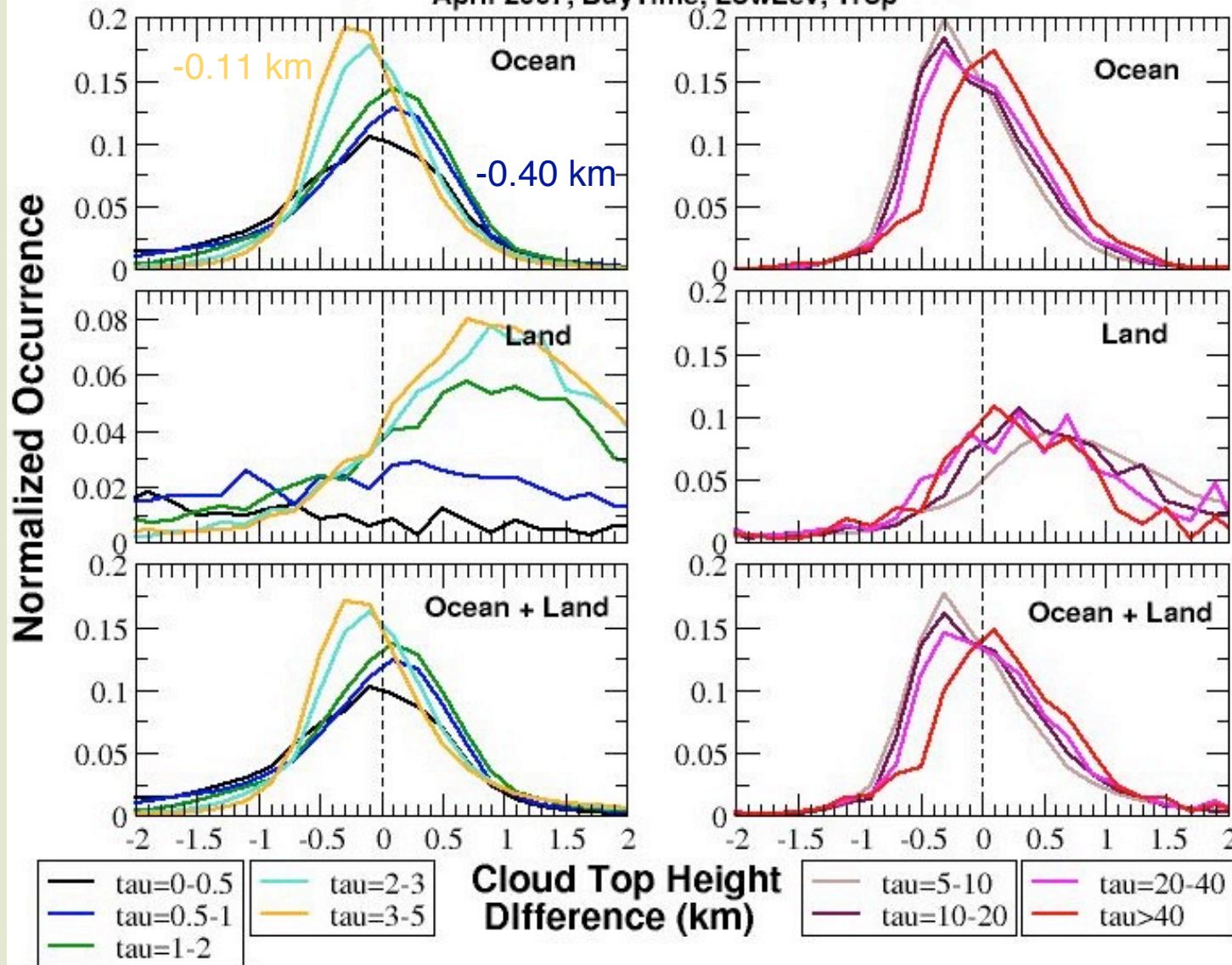


CALIPSO - CERES

Histogram of Cloud Top Height Difference

Calipso - CERES

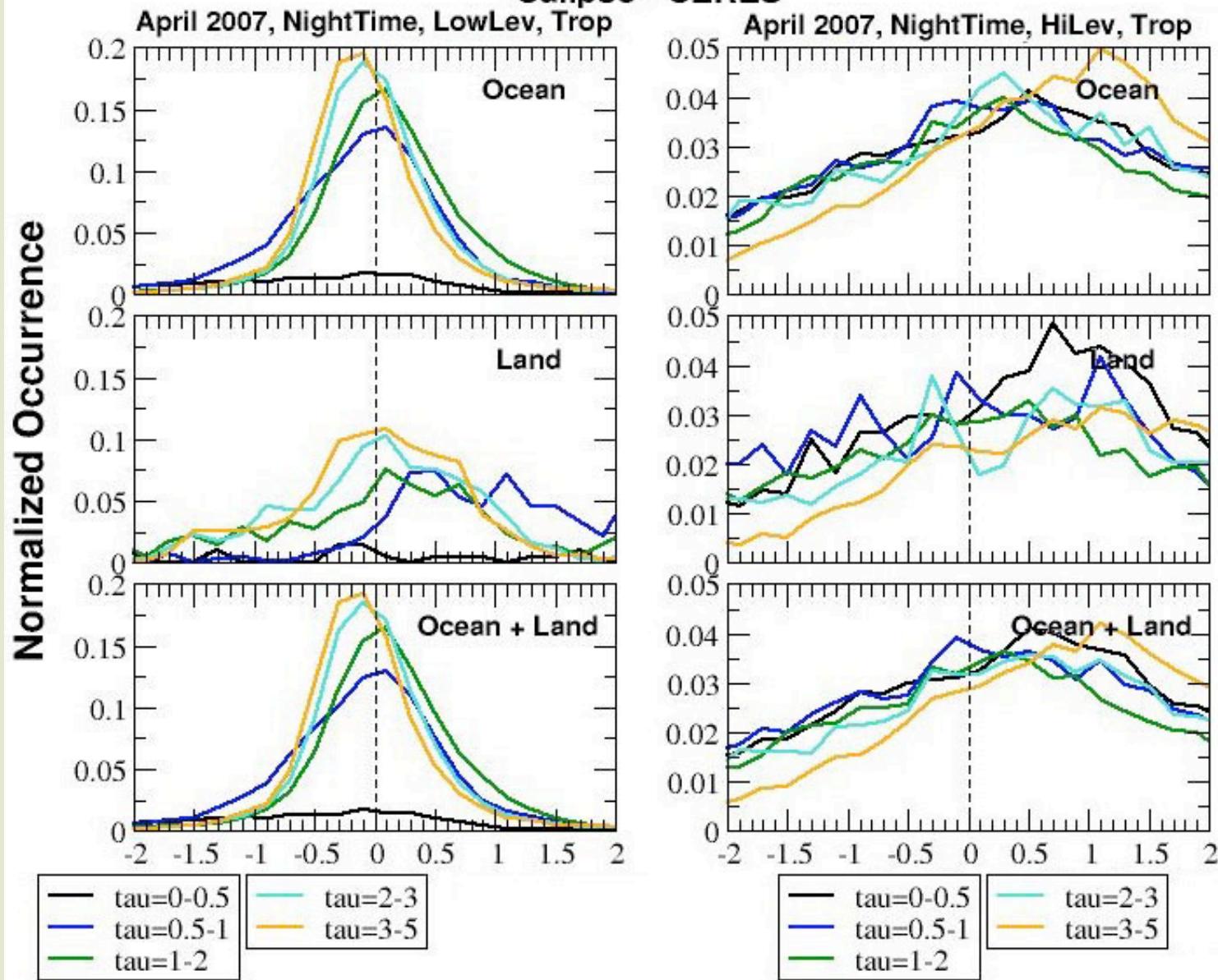
April 2007, DayTime, LowLev, Trop



- Different lapse rates needed over land (5.5/km?) and water (8.0/km?)
- Correction for effective to top?



Histogram of Cloud Top Height Difference Calipso - CERES



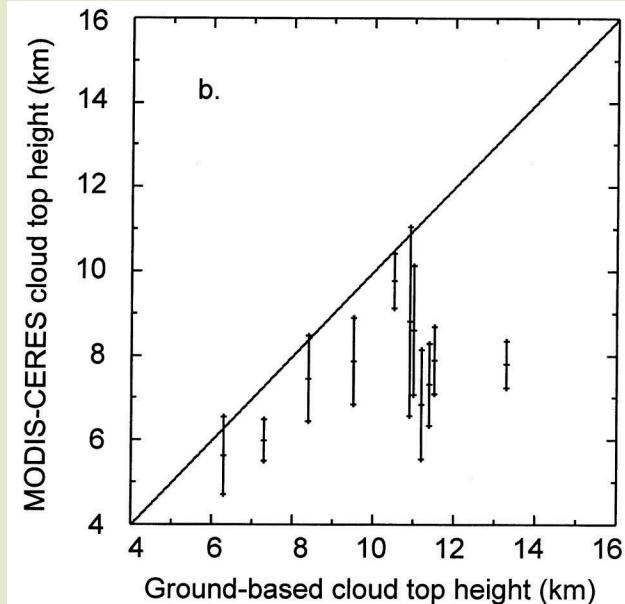
- Need different corrections for cirrus.



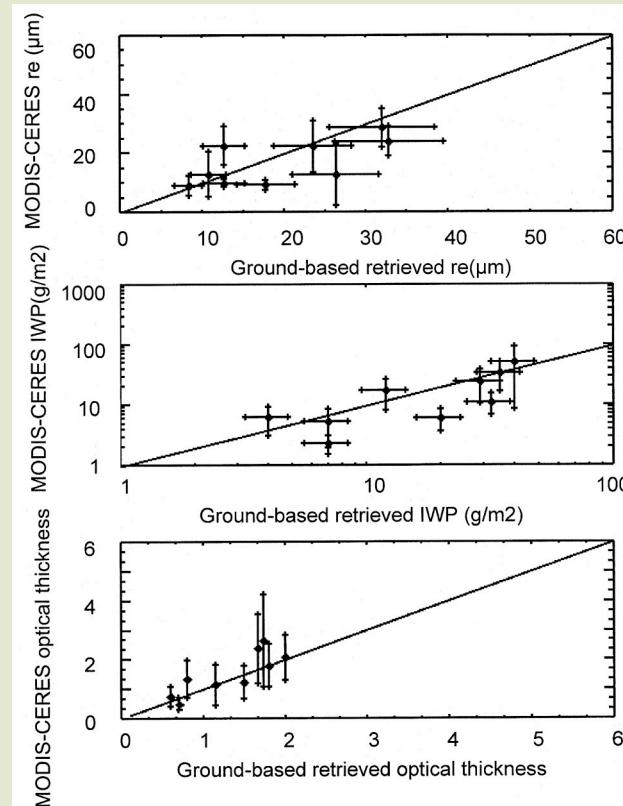
Introducing Variable Phase Functions for Ice

CERES cirrus clouds are too low, tau too large

De a little small, small IWPs look good - what is problem



from Mace et al. (2005)



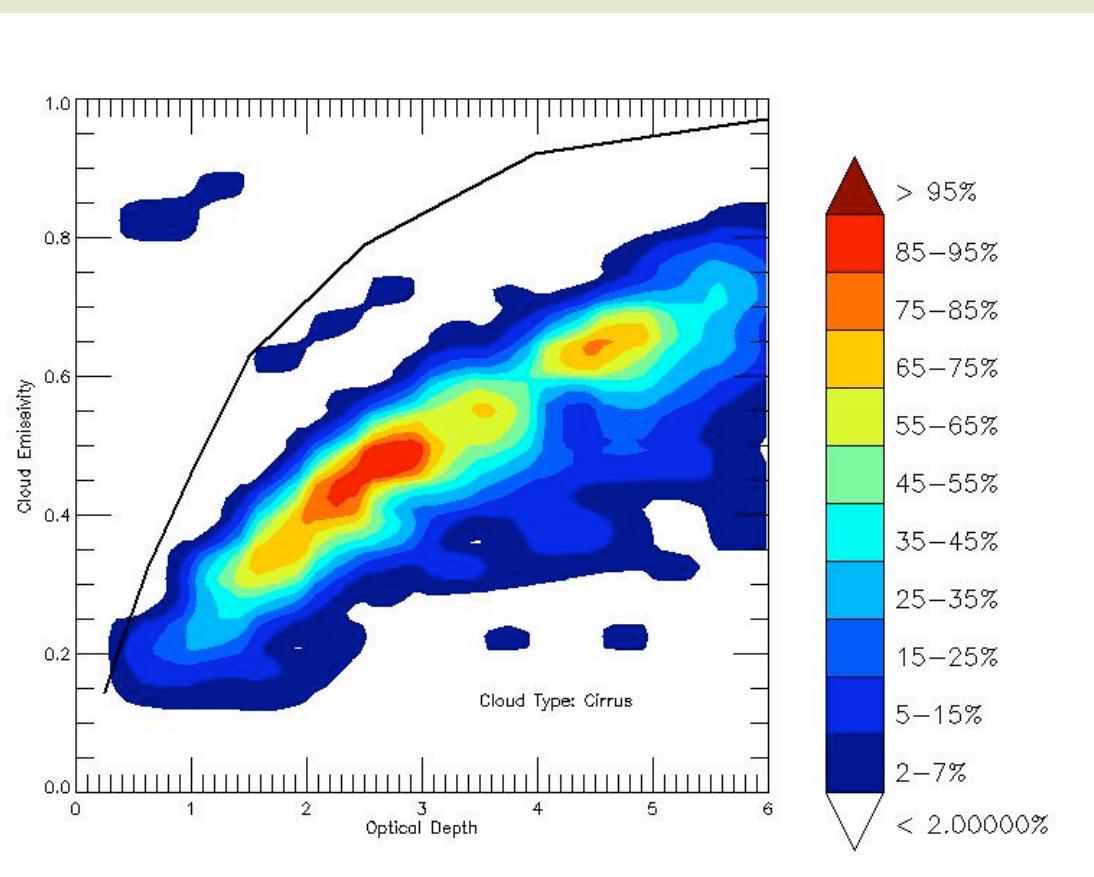
CERES phase functions appear to be as good as any others
- shape not as important as roughness?



MOD06 gets pretty good cirrus heights from CO2-slicing

- but tau is larger than CERES - inconsistent!

MOD06 CO2 cirrus emissivity vs VIS optical depth

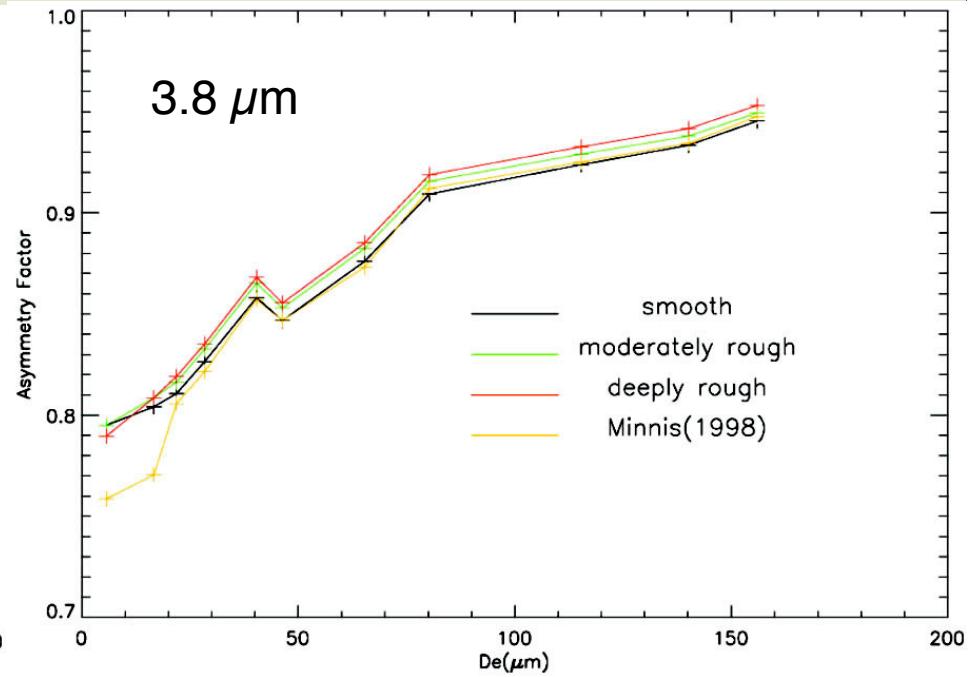
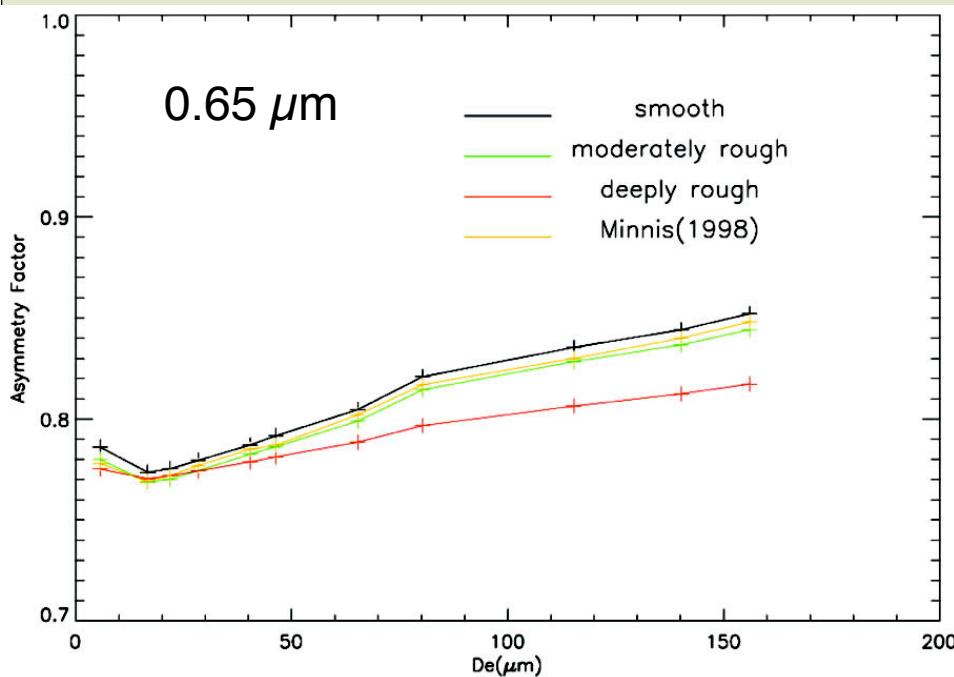


How do we get better heights but same IWP?



Roughened Ice Crystals

- recent measurements indicate $g < 0.8$ in many cirrus clouds, down to 0.75
- roughened ice crystals decrease g for same size and shape



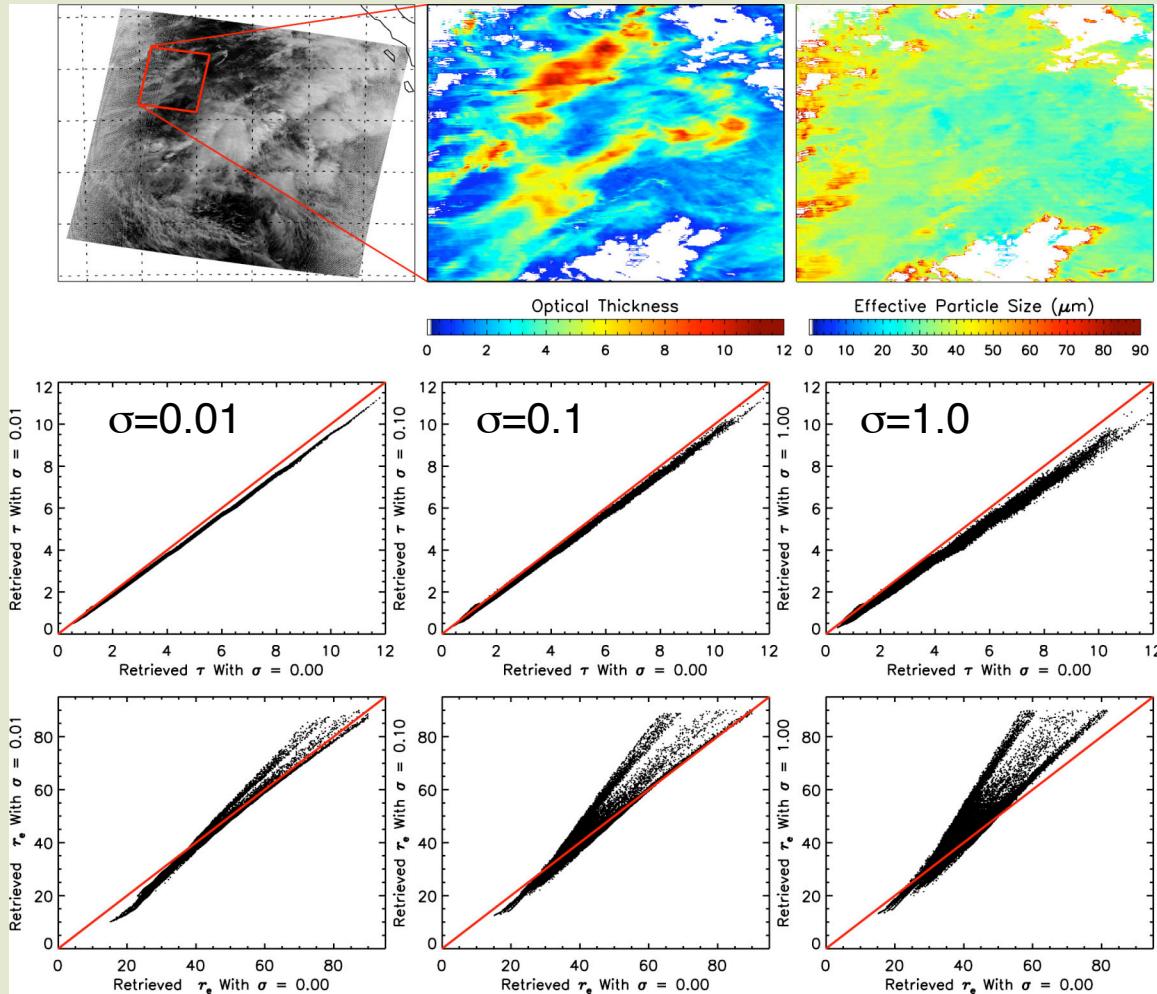
Yang et al. (2007) developed roughened ice crystal phase functions -

- VIS (SIR) asymmetry factors reduced (increased) with roughness
 - =>should yield smaller tau
 - =>De larger, IWP nearly the same



Retrievals Using Roughened Ice Crystal Models

Terra MODIS, Indian Ocean, 0435 UTC, 22 June 2006



Adding roughness to smooth xtals decreases retrieved τ by 5-30% depending on angles.



Edition 3 Retrievals of Thin Cirrus Cloud Properties, Daytime

- Perform VISST & CO₂-slicing retrievals

$$\Rightarrow T_{\text{eff}}, \tau_{\text{sm}}, p_{\text{eff}}, D_{\text{sm}} + T_{\text{co2}}, p_{\text{co2}}, \tau_{\text{co2}}$$

- If single-level and $\tau_{\text{sm}} < 6$, then

- if $p_{\text{eff}} - p_{\text{co2}} > 50 \text{ mb}$, then attempt to find new ice crystal model

- Perform retrieval with VISST-R, where nominal models replaced with roughened models, $\sigma = 1.0$: $\Rightarrow T_{\text{refl}}, g_{\text{ro}}, \tau_{\text{ro}}, D_{\text{ro}}$

- If $T_{\text{co2}} \leq T_{\text{refl}}$, then use results of VISST-R, otherwise

$$\tau = (\tau_{\text{sm}} - \tau_{\text{ro}}) / (T_{\text{eff}} - T_{\text{refl}}) + \tau_{\text{ro}}$$

And so forth for g , D_{eff}

- Retrieval structure has been developed, models will be ready this week



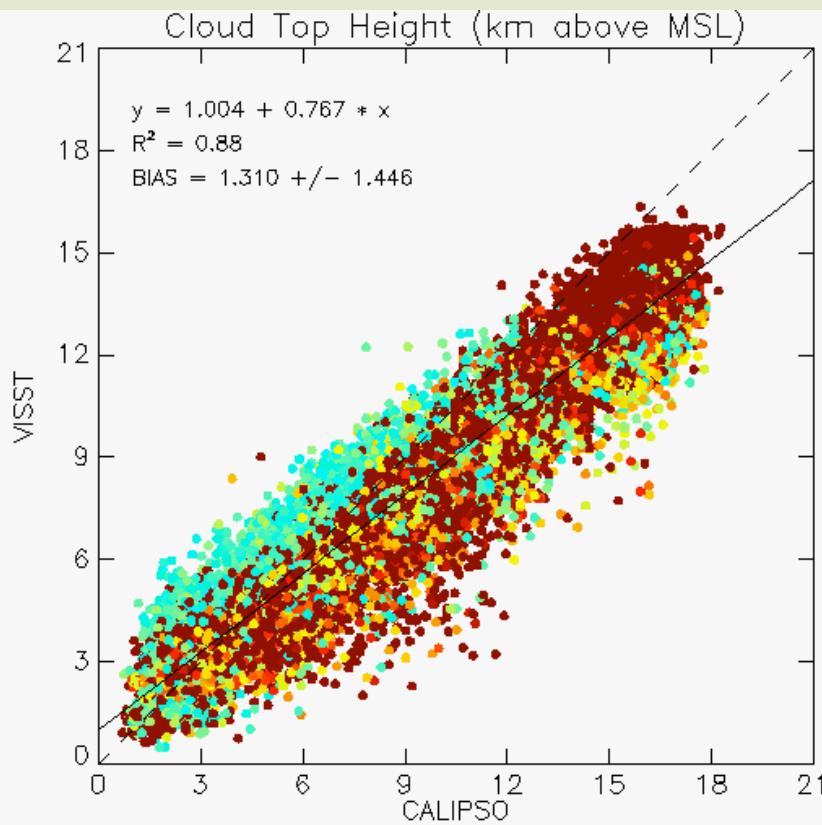
Edition 3 Improvement of SIST Retrievals, Night/Twilight

- Perform SIST & CO₂-slicing retrievals
 $\Rightarrow T_{\text{eff}}, \tau_{\text{sm}}, p_{\text{eff}}, D_{\text{sm}} + T_{\text{co2}}, p_{\text{co2}}, \tau_{\text{co2}}$
- If single-level and $\tau_{\text{sm}} < 6$, then
 - if $p_{\text{eff}} - p_{\text{co2}} > 50 \text{ mb}$, then attempt to find new ice crystal model
- Perform retrieval with SIST-C, where $T_{\text{refl}} = T_{\text{co2}}$, solve for τ, D_{eff}
- Retrieval structure has been developed and being tested

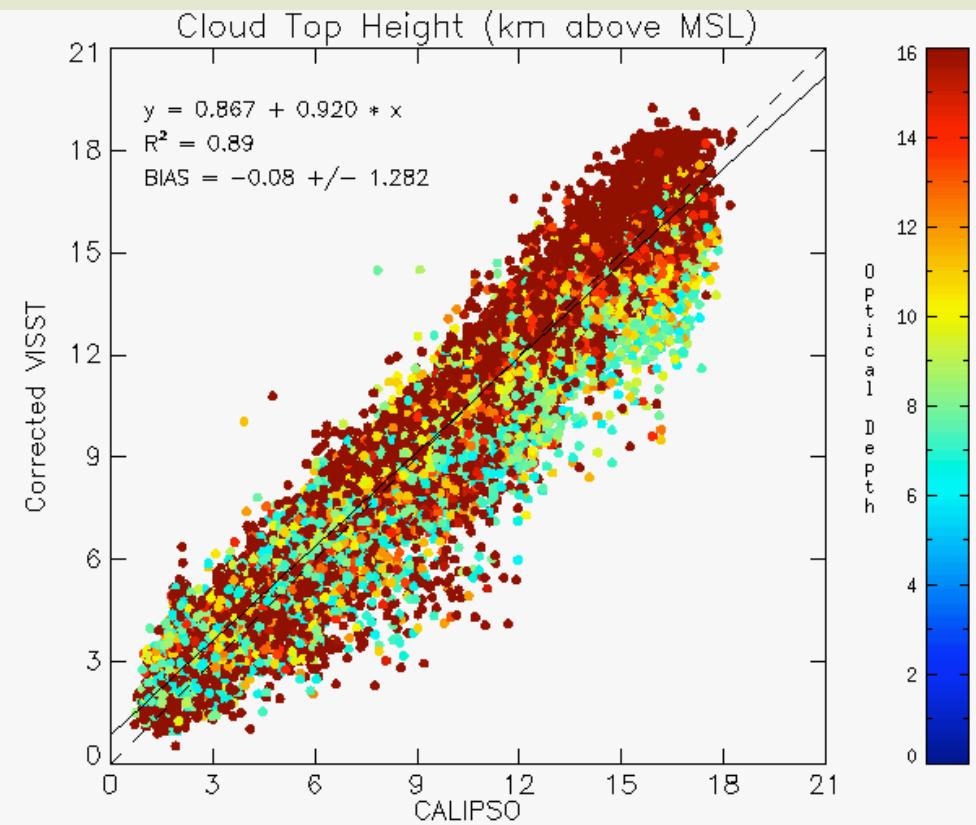


Correcting Cloud-Top Heights for Optically Thick High Clouds

Data for 27 April to make fit



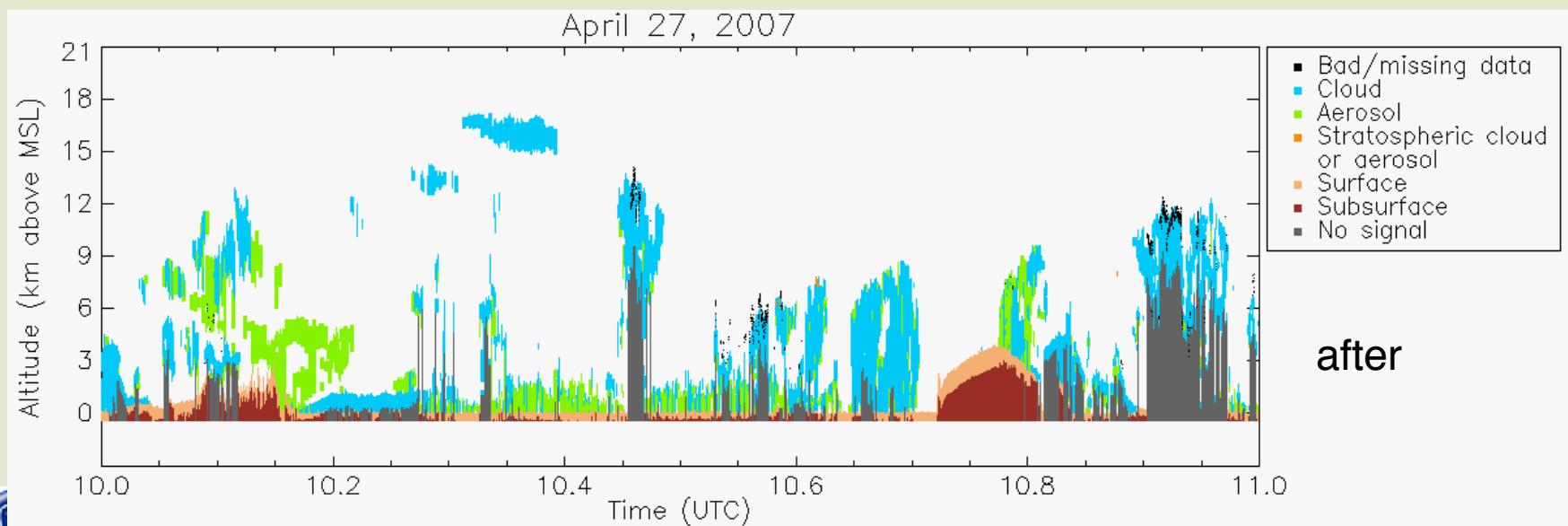
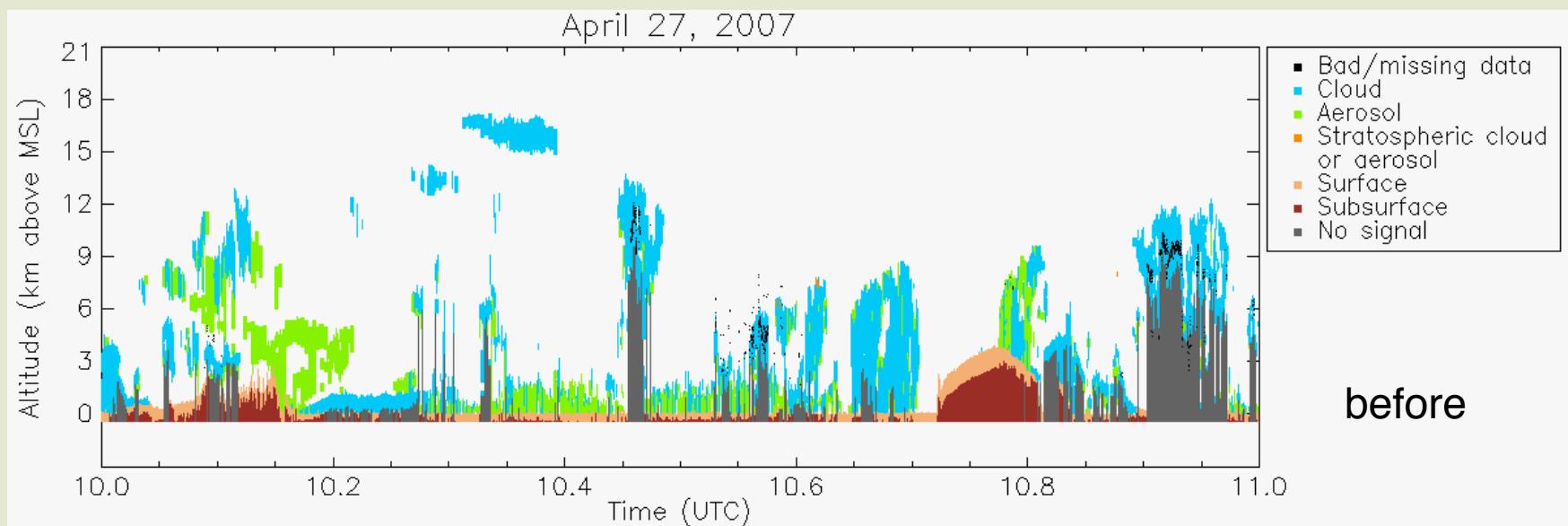
Data for all April using fit



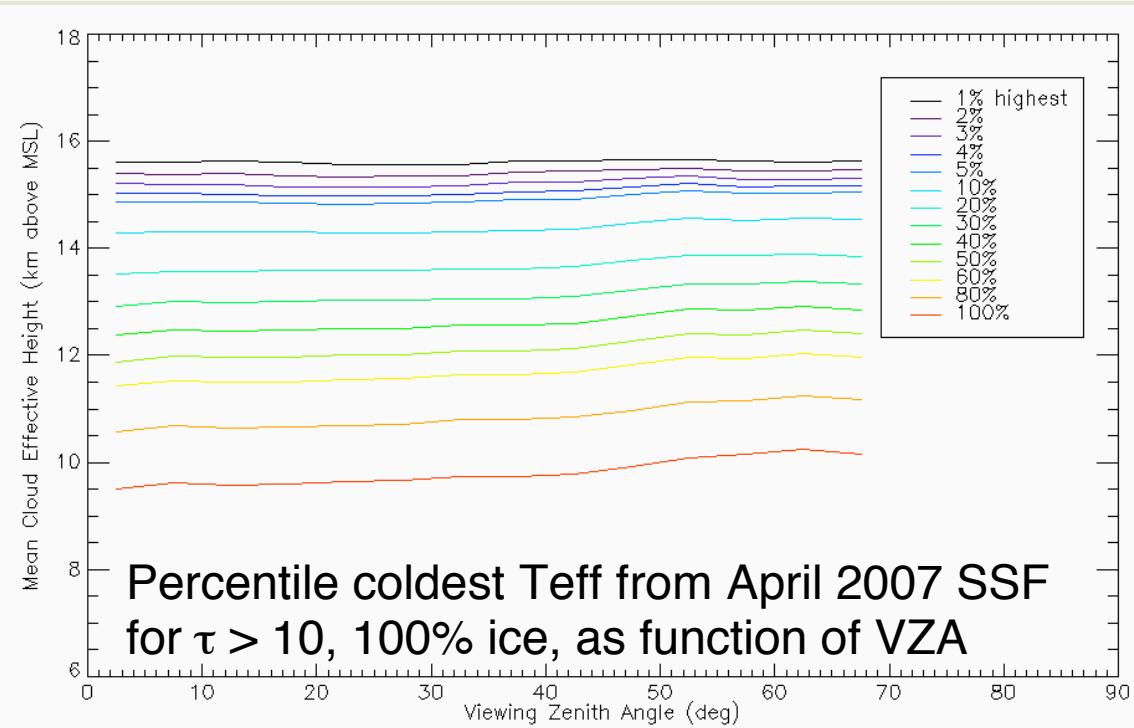
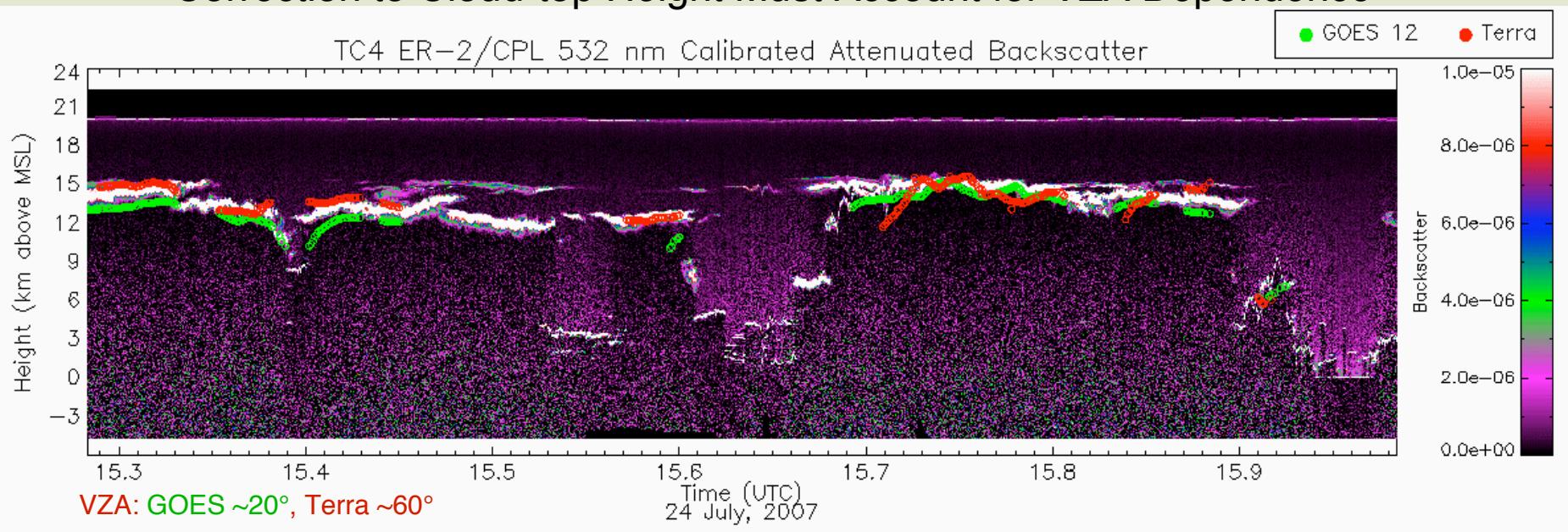
Empirical corrections can be refined with theory and more data slicing to improve accuracies!



Example of improved cloud-top heights



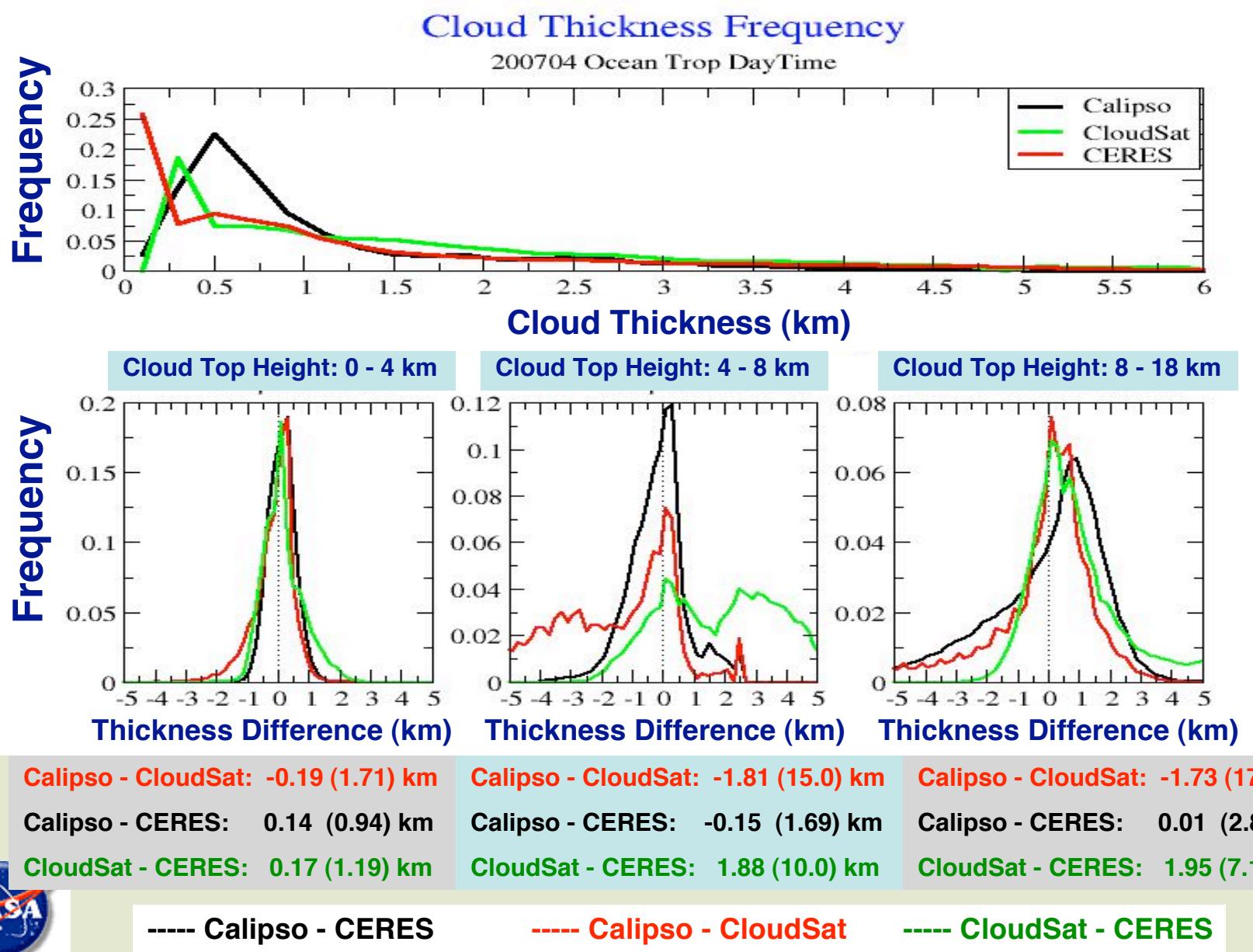
Correction to Cloud-top Height Must Account for VZA Dependence



Height correction will decrease with VZA as effective path length through cloud increases for a given depth from top.



Cloud Thickness Inter-Comparisons (Single Layer)



Thickness Improvements => More Accurate Cloud Base

- Matched MODIS-CALIPSO-CloudSat datasets
 - repeat studies of Minnis et al. (1991), Chakrapani (2002)
- Develop new thickness parameterizations (Beta 2)
 - need CALIPSO opt depth for thin cirrus

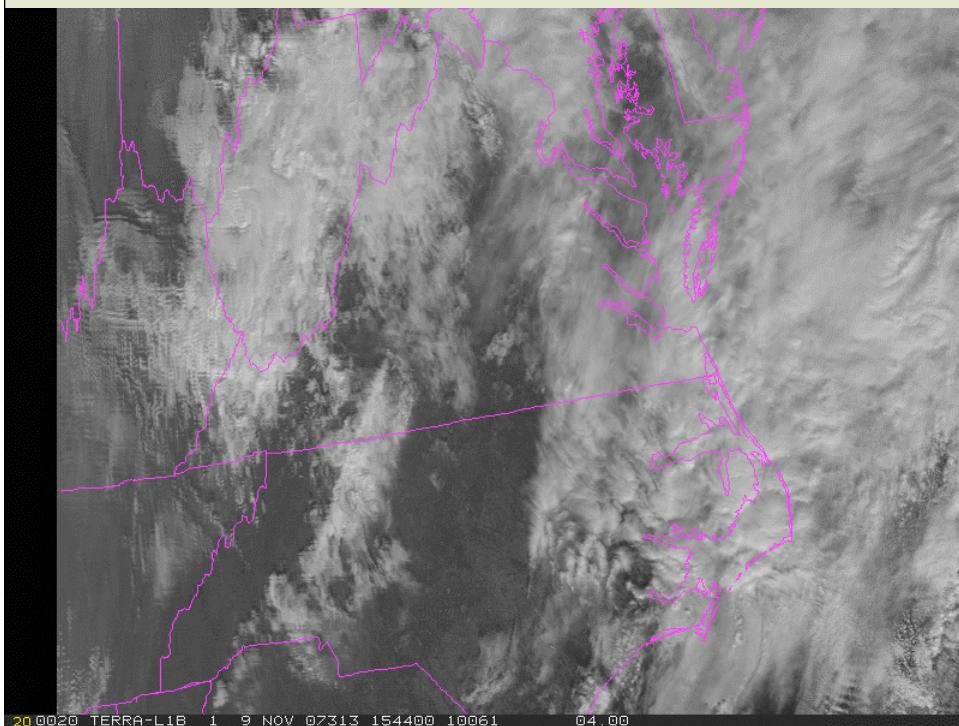


Expanded Optical Depth Models

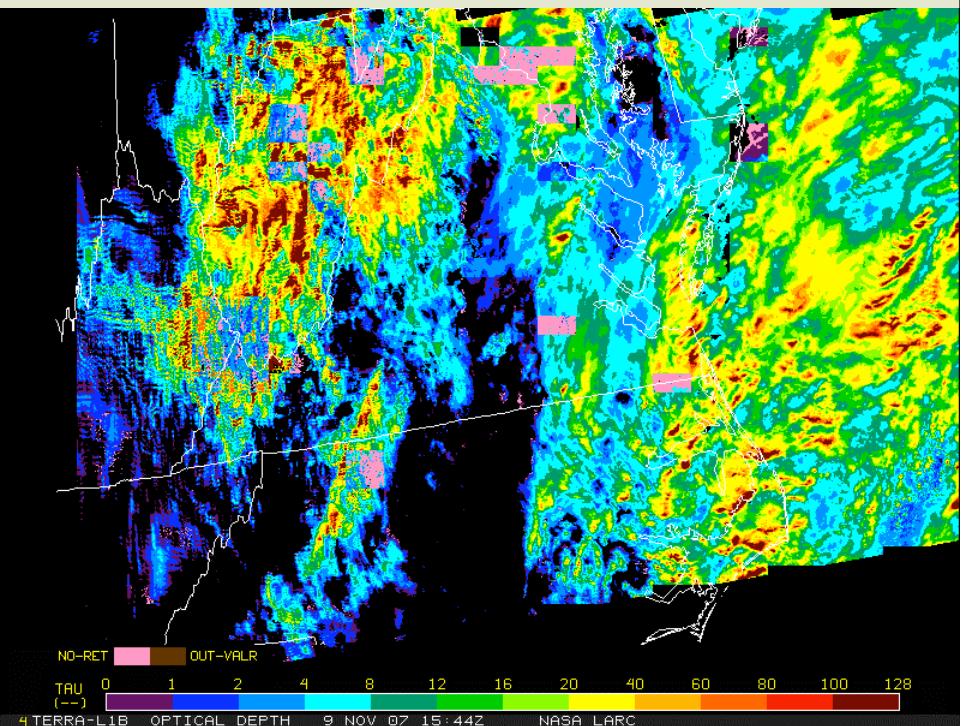
Range in retrieved cloud optical depth increased from 128 to 512

=> increase in LWP & IWP

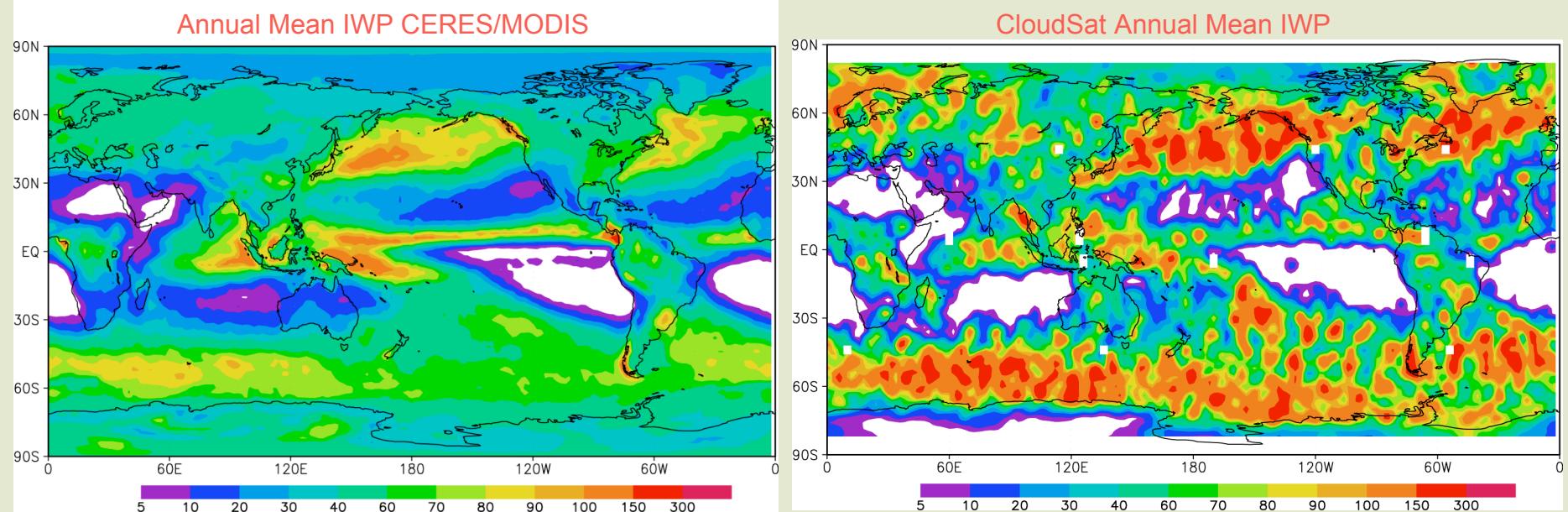
Terra MODIS VIS, 9 Nov 2007



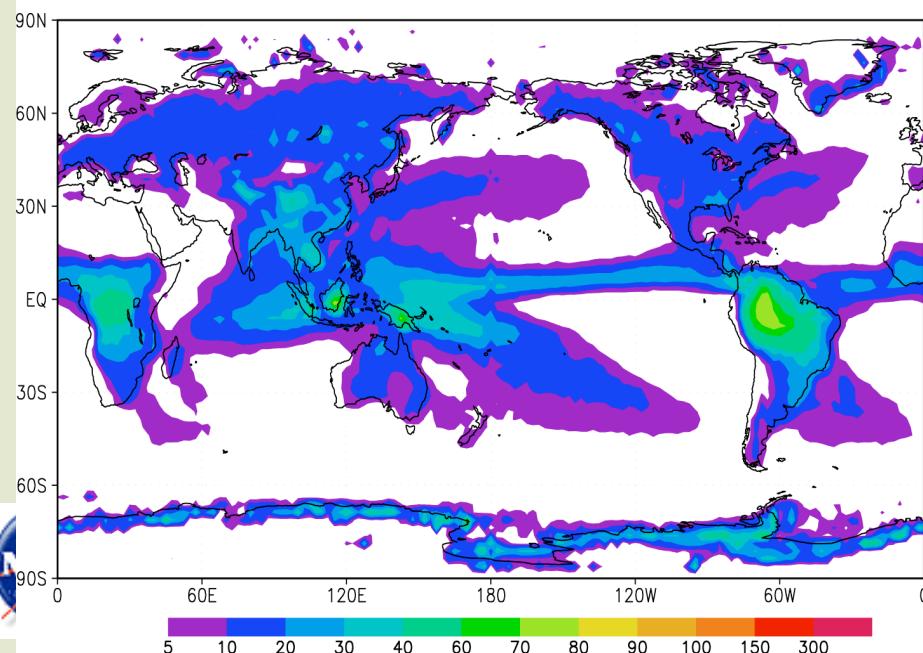
Optical Depth



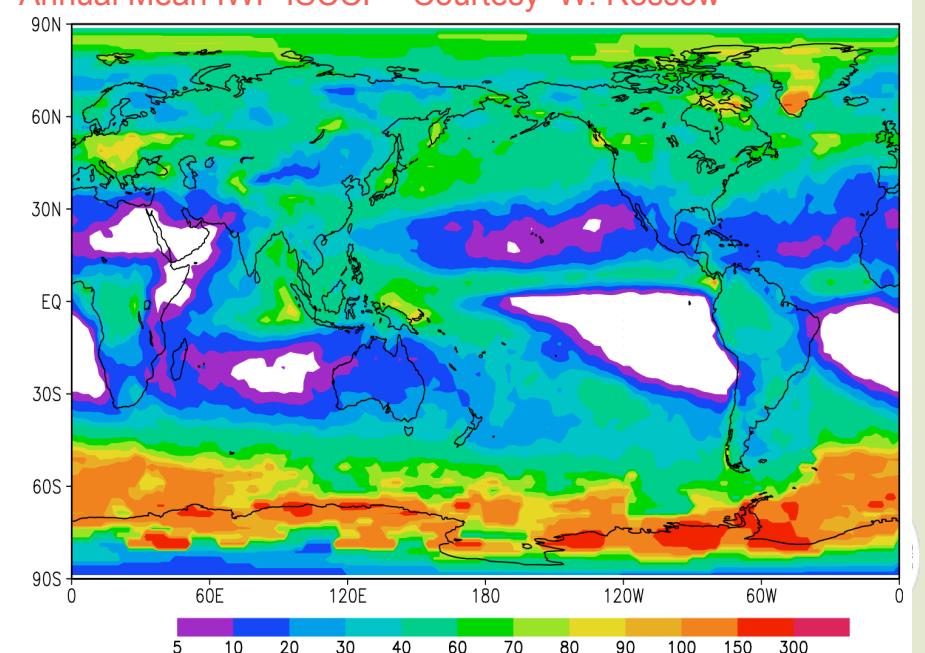
CLOUD ICE WATER PATH (FROM WALISER ET AL. 2007)



Annual Mean IWP NOAA/Microwave - Courtesy H. Meng



Annual Mean IWP ISCCP - Courtesy W. Rossow



Ed3 Ice Water Path

- Increased opt depths => give a better match with CloudSat
 - CloudSat IWP not yet validated, do not know the error
 - CERES IWP is actually smaller because of ML clouds
 - => ~ 42% less in ML clouds
 - => ~85% overall if 35% ML cover
- Users will need to interpret large taus with caution
 - small error in reflectance, big error in tau
 - 1% reflectance difference between Aqua & Terra!



No Retrieval Minimization

- CERES Ed2 no retrieval percentage is ~4% for nonpolar areas
 - retrieved cloud fraction = 0.58
 - compare to 0.54 for MODIS products (less for 1.6, 2.1 μm)
- To reduce no retrievals in Ed3
 - use LBTM (VIS & IR only, assume particle size)
 - use IR techniques for thin clouds
- Test runs indicate LBTM reduces no retrievals to < 1%
 - IR techniques (SIST/CO₂) needed for remainder
 - recalculate clear sky reflectances/sfc temps?



New CO₂ Method

- Applicable to SL & ML clouds both day and night
- Faster than 4-channel method
- Applicable to many satellites (any imager with 11 and 13.3 μm)
- Details - wait for Chang Co-I Report

Previous

- BTD & CO₂ technique - ~85% accurate in detecting SL clouds
 - minimal skill at detecting ML clouds

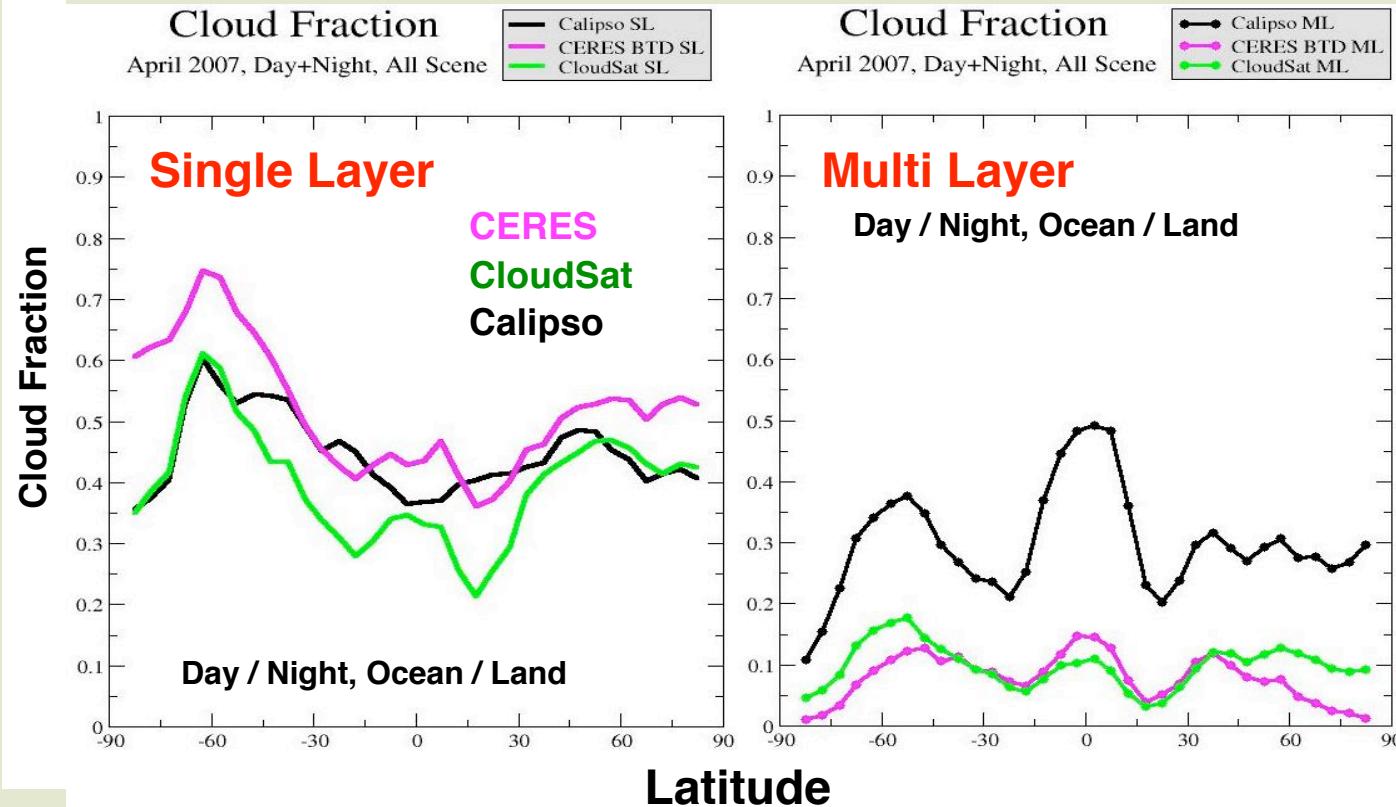


Multilayer cloud detection and retrieval

- Edition 3 will use new CO₂-slicing/VISST & BTD overlapped cloud detection methods
 - only detects ML clouds when upper cloud $\tau < 4$
 - uses compact CO₂ retrieval technique (see Chang talk)
- Mechanics of method currently operational, but many revisions have occurred
 - refinement is ongoing using CALIPSO/CloudSat
 - validation planned using same datasets & TC4
- Offline studies using MW & VISST (MCRS) over ocean for thicker clouds
 - cancelled (proposal not funded)



Single and Multi Layer Cloud Fractions Proto-Ed3 (April, 2007)



Day Time

Multilayer Cloud Fraction

Night Time

	Calipso	CERES	CloudSat
Ocean	0.32	0.11	0.10
Land	0.32	0.13	0.09

	Calipso	CERES	CloudSat
Ocean	0.34	0.07	0.11
Land	0.31	0.08	0.08



CERES Multilayer Cloud Retrieval Development

Objective:

- *Retrieve the upper-layer cloud top height*
- *Retrieve the lower-layer cloud top height*
- *Determine multi-layered cloud properties*

Challenge:

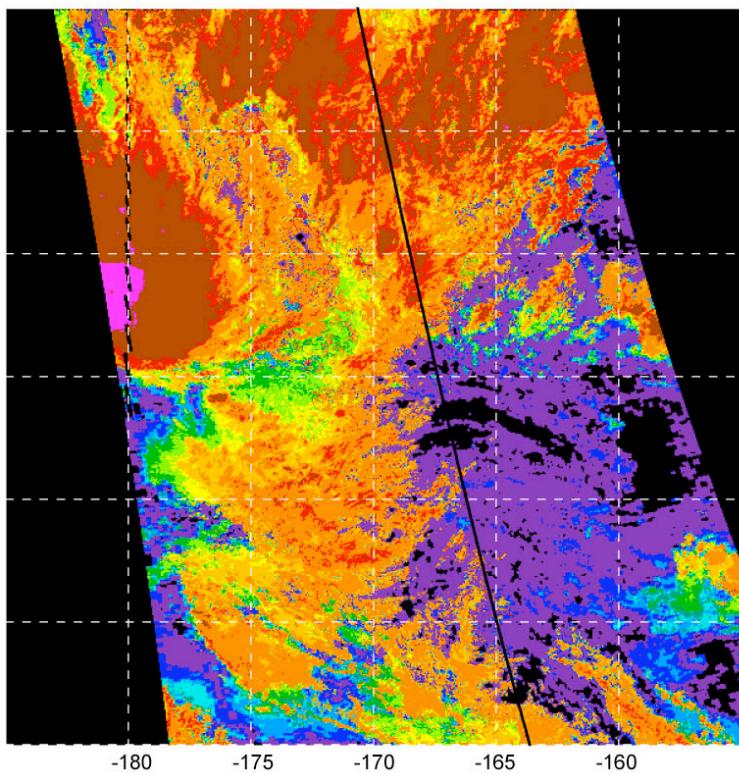
- *Ill-posed problem*
- *Individual pixel cloud retrieval approach*
- *Retrieval (not a guess) of the lower-layer height*
- *Processing time and data volume*

Proposed Method:

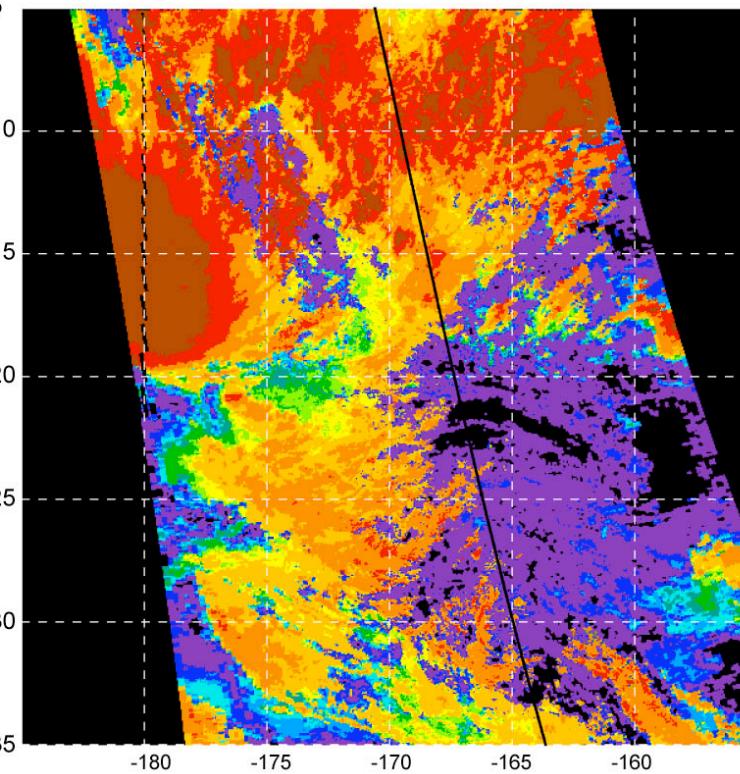
- *Use a pair of 11- μm and 13.3- μm channels to retrieve upper-layer and lower-layer cloud top heights*
- *Implement the new 11-/13.3- μm -retrieved cloud top heights into the updated VISSST cloud retrieval algorithm*

Comparison of CERES and MYD06 Cloud Top Heights

CERES 1-km, 11.0/13.3 μ m



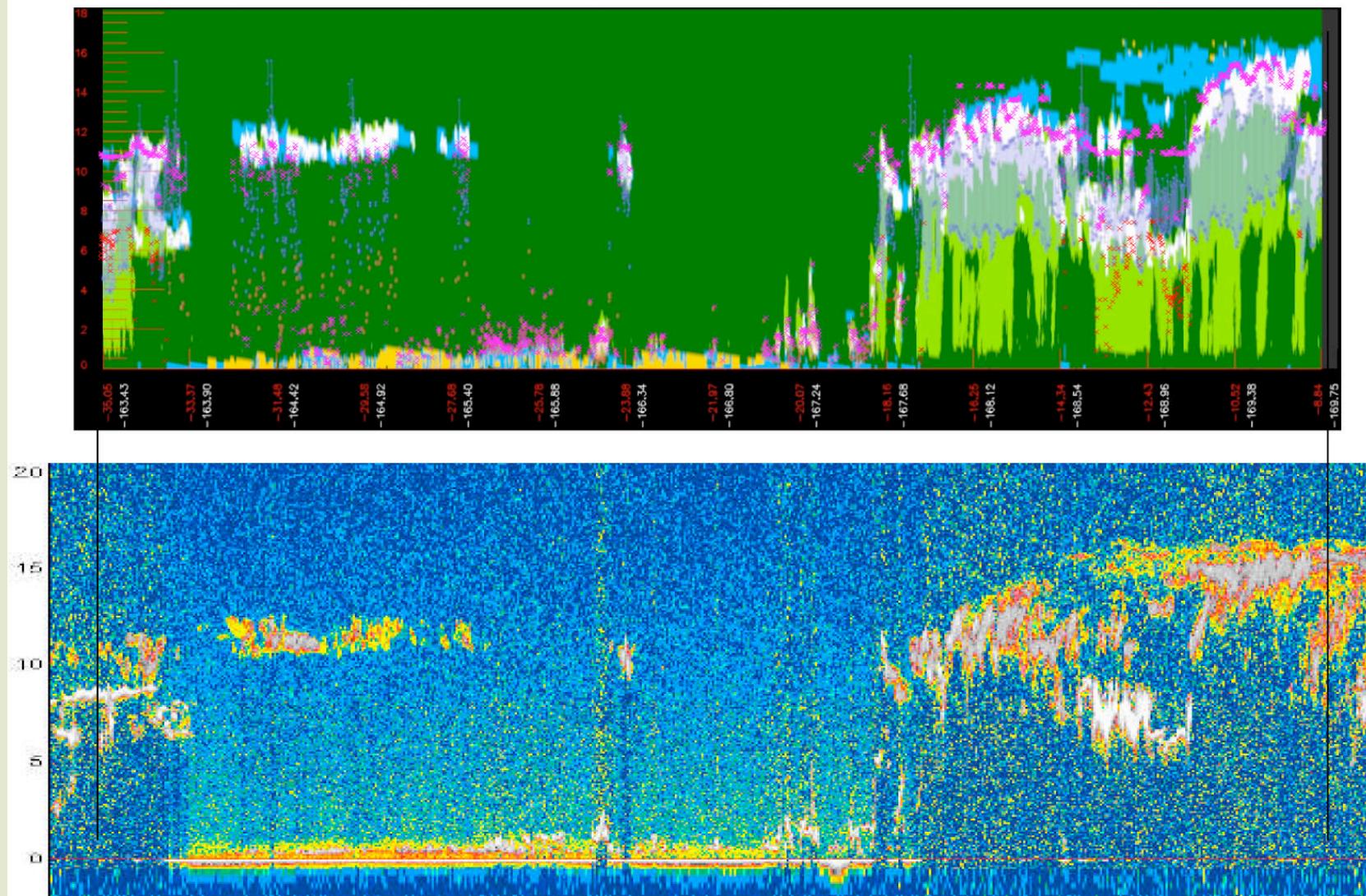
MYD06 5-km, 11.0/13.3/13.6/13.9/14.2 μ m



CERES 2-channel CO₂ yields comparable cloud top heights to 4-channel method



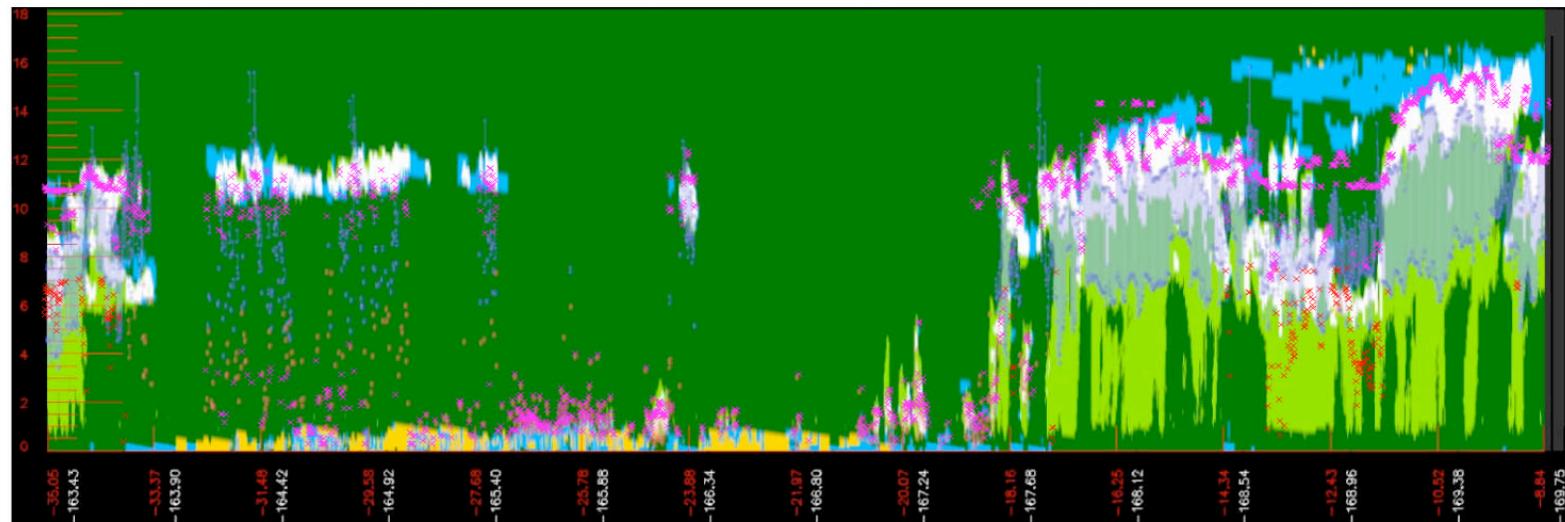
Comparison of CloudSat-CALIPSO with CO2-based Retrieval



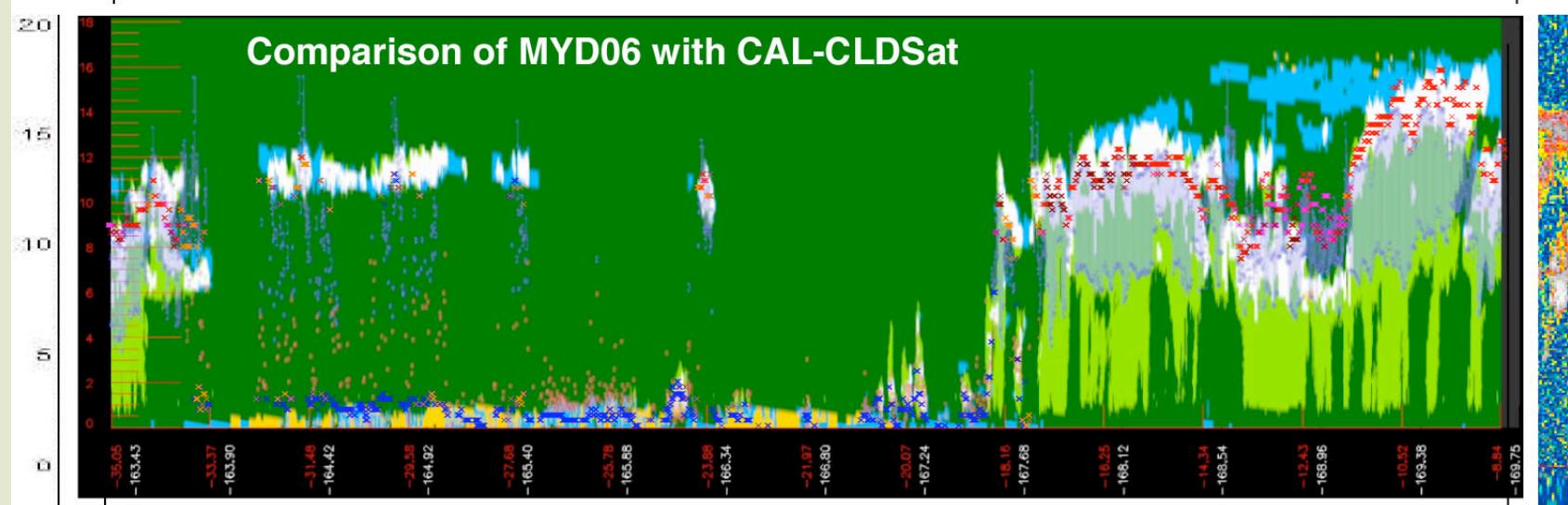
Does not detect all ML clouds, but gives improved heights of higher level clouds



Comparison of CloudSat-CALIPSO with CO2-based Retrieval



Comparison of MYD06 with CAL-CLDSat



2-channel heights better than 4-channel values in many cases



Edition 3 Betas

- **Cloud mask improvements**
 - CO₂ method working
 - clear-sky model, threshold, polar transition improvements
- **Cloud retrieval improvements**
 - multippectral retrievals, fewer no retrievals
 - adjust lapse rates, include CO₂ heights
 - new ice cloud phase functions
 - expanded tau range
- **Multilayer cloud detection & retrieval**
 - New code working, need to replace old CO₂ code and test
 - need CALIPSO opt depth for assessment
- **Hi-res cloud detection/retrieval of low clouds (250 m - 1 km)**
 - Beta 2
- **New thickness parameterization**
 - Beta 2

